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Thank you from the Editors

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Front cover: Cool temperate rainforest at Tarra Bulga National Park. Photo by Maggie Riddington.
Back cover: Sheila Houghton. Photo by Neville Houghton.

Uptake and toxicity of arsenic: *Bryum dichotomum* Hedw. — a case study

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Abstract

Bryophytes have been used widely as biomonitors to map distribution of pollutant concentrations for many years, but their reliability has been questioned. One issue was the variability of uptake capacity within a species. Many potential reasons have been suggested for this, both intrinsic and extrinsic. This paper provides a brief review of arsenic uptake and tolerance within plants, particularly bryophytes, and examines the variability in uptake of arsenic using *Bryum dichotomum* Hedw., a moss, as a model organism. Samples were used from two sites, one with low and one with high arsenic emission levels. Differences in uptake were noted and it is suggested that these differences are the result of acclimation to exposure levels at the site from which they were removed. This acclimation could be simple hardening common to many plants or genetic differentiation into ecotypes. The findings of this study have implications with regards to the suitability of bryophytes as biomonitors of metal pollution. (*The Victorian Naturalist* **131**(6), 2014, 192-203)

Key words: *Bryum dichotomum*, arsenic, biomonitor, metal uptake, metal pollution

Introduction

The element arsenic, is ranked 20 in abundance in the earth's crust and its presence considered both a major health concern and pollutant on a global scale (Cullen and Reimer 1989; McArthur 1999). In the past, arsenic was used in a number of agricultural pesticides. Understandably, therefore, some of the first investigations into the effects of arsenic on plants were carried out on crop plants in an endeavour to determine whether crops sprayed with pesticides containing arsenic would affect those consuming them (Murphy and Aucott 1998; Wells and Gilmour 1977; Woolson *et al.* 1971). These studies determined that certain crop plants retained arsenic above and beyond that found in the soil. Because of this, pesticides that contained lead arsenate were banned in most developed countries during the 1980s (Peryea 1998) and have since been replaced with herbicides containing the less toxic form monosodium methyl arsenate (World Health Organisation (WHO) 2005).

Interest in the tolerance of plants to arsenic has continued to grow, especially because tens of millions of people are exposed to high levels of arsenic in West Asia through the continued consumption of contaminated food plants (Roychowdhury *et al.* 2003; Roychowdhury *et al.* 2002). The uptake of arsenic by plants may have caused concern for the public health because of contaminated food sources, but it also provided a possible means of removing arsenic from contaminated environments. While the research on use of plants as a remediator for arsenic contaminated soils started back in the 1970s, more recently (2000 to 2009) a wealth of studies have been published (Table 1), although only few on bryophytes. These studies have shown that hyperaccumulators can be found throughout the plant kingdom and include flowering plants, ferns and bryophytes. Plant species vary in their capacity to take up arsenic, and taxonomic affinity does not necessarily translate to similar uptake abilities. For example, the fern species *Pteris vittata* can hyperaccumulate 3894 µg of arsenic per gram of dried plant material (µg/g) (Zhang *et al.* 2002), but the congeneric species *Pteris tremula* and *Pteris straminea* can take up only 16.6 and 78.0 µg/g respectively (Ma *et al.* 2001; Meharg 2003). Koch *et al.* (1999) examined arsenic content of a wide variety of plants and found that mosses contained the highest levels per unit of dried weight but species varied in uptake capacity, 490–1229 ppm dry weight. Floyed (2010) also showed this variation in uptake capacity, as

Table 1. Examples of studies investigating arsenic in various plant groups.

Authors	Plant groups investigated	number of species	Area of study
Samecka-Cymerman and Kempers (1994)	Bryophytes	5	Bioindication
Koch *et al.* (1999)	Algae	2	Biomonitoring
	Bryophytes	1	
	Lichens	4	
	Fungi	3	
	Flowering plants	41	
Koch *et al.* (2000)	Bryophytes	1	Arsenic speciation
	Flowering plants	12	
Ma *et al.* (2001)	Ferns	1	Hyperaccumulation
Francesconi *et al.* (2002)	Ferns	1	Hyperaccumulation
Lombi *et al.* (2002)	Ferns	1	Arsenic distribution and speciation within fronds
Visoottiviseth *et al.* (2002)	Grasses	4	Accumulation/ hyperaccumulation
	Flowering plants	21	
	Ferns	6	
	Trees	521	
Zhang *et al.* (2002)	Ferns	1	Arsenic speciation and distribution within plants
Zhao *et al.* (2002)	Ferns	11	Hyperaccumulation
Aceto *et al.* (2003)	Bryophytes	1	Bioindication
Meharg (2003)	Ferns	45	Accumlation/ hyperaccumulation
	Fern allies	45	
Robinson *et al.* (2003)	Flowering plant	1	Uptake
Salido *et al.* (2003)	Ferns	1	Phytoremediation
	Flowering plants	1	
Warren *et al.* (2003)	Flowering plants	6	Uptake
Zhang *et al.* (2004)	Ferns	1	Characterisation of arsenic uptake
Duan *et al.* (2005)	Ferns	1	Characterisation of arsenic uptake
Fayiga and Ma (2005)	Ferns	2	Uptake
Robinson *et al.* (2006)	Ferns	5	Hyperaccumulation
	Flowering plants	5	
Van *et al.* (2006)	Ferns	1	Accumulation
Wei and Chen (2006)	Ferns	2	Accumulation
Catarecha *et al.* (2007)	Flowering plants	1	Accumulation
Craw *et al.* (2007)	Bryophytes	4	Accumulation
	Ferns	4	
	Flowering plants	12	
Shahraki *et al.* (2008)	Flowering plants	5	Phytoremediation

have other studies. Koch *et al.* (1999), Aceto *et al.* (2003) and Craw *et al.* (2007) found *Funaria hygrometrica*, *Bryum argenteum* and *Pohlia wahlenbergii* respectively had arsenic compositions up to 350 μg/g, 10.9 μg/g and 29 000 μg/g, the latter value being over the hyperaccumulator threshold of 1000 μg/g.

Coping mechanisms for arsenic tolerance varies. Some vascular species such as the tomato *Lycopersicon esculentum* Mill. var. *esculentum*, store arsenic within their root system (Carbonell-Barrachina *et al.* 1997), while other species, such as *Pteris vittata*, transport arsenic from the roots to the shoots where it is stored (Zhang *et al.* 2002). The storing of arsenic in the roots is considered a sign of arsenic exclusion (Carbonell-Barrachina *et al.* 1997), while the translocation of arsenic from the roots to the shoots, especially to senescing leaves, is seen as a means of detoxification as arsenic is removed from the plant at leaf fall (Dahmani-Muller *et al.* 2000). In yet other fern species, it appears that arsenic is actively removed via translocation from the senescent frond to younger fronds (Francesconi *et al.* 2002).

Within marine organisms, arsenic is normally found in organic forms such as arsenosugars in algae, and arsenobetaine and arsenocholine in fish, molluscs and crustaceans (Francesconi *et al.* 1994; Maeda 1994). In vascular plants, arsenic is normally stored as the more toxic inorganic forms of arsenate (As[V]) and arsenite (As[III]) (Koch *et al.* 1999; Koch *et al.* 2000; Zhang *et al.* 2002). Because of the chemical similarities of arsenate and phosphate, arsenic competes against phosphate for the phosphate uptake system (Macnair and Cumbes 1987; Meharg and Macnair 1990, 1991; Wells and Richardson 1985), and is taken up through vascular plant root systems as arsenate (Zhang *et al.* 2002). Once arsenate has entered the plant, it is reduced to arsenite as a means of detoxification within the plant (Zhang *et al.* 2002). Arsenite, while more toxic, is bound to ligands (or chelators) and then can be compartmentalised in the vacuoles which help stabilise the complexes due to their acidic nature, thereby avoiding damage to the cells (Meharg and Hartley-Whitaker 2002). Thus, as long as the samples are treated so that both arsenate and arsenite may be measured, a true indication of arsenic content may be achieved.

Certain bacteria and yeasts reduce arsenate to arsenite, and can efflux arsenite from their cells through transporters (Rosen 1999). *Saccharomyces cerevisiae* also can form complexes between arsenite and glutathione which then can be actively transported into the vacuole through a specialised transporter (Rosen 1999). It is speculated that the arsenite is bound to phytochelatins which are transported into the vacuole (Meharg and Hartley-Whitaker 2002). While arsenic phytochelatins are not stable under either neutral or alkaline conditions, they are stable under acidic conditions, which normally are found within the vacuole (Schmoger *et al.* 2000; Sneller *et al.* 2000).

Uptake and toxicity studies can resolve a number of issues. For example, they may determine the sensitivity of a species to the element in question by determination of its lethal dose; they may help to determine if species will react in a progressive manner to a particular substance under sequential concentration loads; they can determine if reactions vary based on where samples originated. These are important questions that should be answered with respect to a species that is used as a biomonitor as it may help explain the sometimes confounding results of fieldwork. Lichens acclimated to different concentrations of an element are well known to display different sensitivities to that element (Bennett 2002; Freitas *et al.* 1999; Herzig 1993; LeBlanc *et al.* 1972; Loppi and Bonini 2000; Nieboer *et al.* 1977; Reis *et al.* 2002; Seaward 1995). This means one cannot simply infer that the behaviour of a species in one area reflects the behaviour of the same species in another area. The same concept generally is applicable to plants, which undergo the process of 'hardening' to become acclimated to changed conditions (Raven *et al.* 1992). This is independent of the findings of Shaw (1994) who postulated that different ecotypes of a species evolve as a response to natural selection in contaminated sites, over a few years, resulting in a species genetically acclimated to different pollutant levels as opposed to only physiologically acclimated. In the laboratory, it is possible to isolate effects to a single element or a specific combination of elements under controlled conditions. In the field, an organism responds to all factors it experiences, including synergistic effects. It can be useful to have an understanding of an organism's behaviour under controlled conditions to provide insights into field data.

Floyed (2010) showed that *Bryum dichotomum* was a moss common to urban streetscapes, occurring at 65 of 88 sites and during any season. Further, it occurred at 42%, 68% and 67% of the sites that released low, medium, and high levels of arsenic respectively and was identified as a hyperaccumulator, being able to accumulate up to 15 134 μg/g arsenic to plant weight (soil concentration was 409 μg/g). This suggests it has potential as a biomonitor of arsenic pollution and should be investigated further. Other species, for example, the liverwort *Chyloscyphus semiteres* var. *semiteres*, also accumulated high levels of arsenic, but were not deemed as ideal samples for further study, either because they were not widespread or because they were not present throughout the year. Uptake of arsenic by *B. dichotomum*, however, was variable and many possible reasons for this were identified. Laboratory controlled investigations help to explain this by removing external environmental

influences on uptake, thereby showing whether biology of the organism was the cause of such variation.

This study examined the behaviour of *B. dichotomum* in terms of its sensitivity to arsenic by determining whether samples acclimated to high levels of arsenic and samples acclimated to low levels of arsenic varied in:

1. the amount of arsenic they accumulated;
2. rate of uptake; and
3. cell viability when exposed to a range of arsenic concentrations.

It is hypothesised that there will be a difference in each instance based on the concept that the species can become acclimated, either physiologically or through development of ecotypes.

Method

Study sites

Bryum dichotomum was collected in the summer of 2006 from the streetscapes of two study sites within Victoria, the Commonwealth Serum Laboratories (CSL) in Parkville, which emits 0.012 kg of arsenic per year, and the Austin Hospital (Austin) in Alphington, which emits 1.1 kg of arsenic per year. The CSL is located near the centre of Melbourne, while the Austin Hospital is east/north east of the CBD. Both sites have streetscapes on all four sides and are surrounded by a combination of other businesses and residential housing. Both experience the same weather: summer – 13.9 to 25.3°C; autumn – 10.8 to 20.3°C; winter – 6.5 to 14.1°C; spring – 9.5 to 19.5°C (Australian Bureau of Meteorology (BOM): http://www.bom.gov.au/climate). Mean monthly rainfall for summer, autumn, winter and spring were 49.1, 47.8, 47.0 and 56.5 mm respectively.

Sampling

At each site, samples were collected from a single large colony and transported back to the laboratory where they were carefully cleaned of particulate matter with the aid of a fine paint brush and an Olympus SZ-PT dissecting microscope.

Culturing

Bryophyte toxicity to three concentrations of arsenic was tested: 100 ppb, 1000 ppb and 10 000 ppb arsenic. These were standard concentrations for toxicological studies of arsenic by the WHO (2000). A control sample for each site was exposed to double distilled water. For each test group, the following time course of exposure was conducted: 0, 1, 2, 4, 8, 12 and 24 hours after Pickering and Puia (1969) who noted that the largest amount of zinc was taken up within the first 24 hours and that at least 50% of zinc absorbed at equilibrium was done so within the first hour for the aquatic moss *Fontinalis antipyretica* L. ex. Hedw. This was replicated three times.

Ten stems of *B. dichotomum* were used per vial. Material was incubated in a Constant Temperature Cabinet using NEC Tri-phosphor 30 watt fluorescent tubes under constant lighting. Vials used for culturing were first washed manually, dried, and then treated with a two part acid wash consisting of an initial 24 hour wash in 1.2M HCl, followed by a 24 hour wash in 10% HNO_3. They were then rinsed in de-ionised water, dried and stored in sealed containers until used.

Viability testing

A total of five mature leaves were sampled from the topmost portion of stems from each culture sample, mounted onto slides and stained with Neutral Red (0.1%) to determine tissue viability. Neutral Red is taken up by the vacuole in viable cells (Fig.1a) (Castro-Concha *et al.* 2006), thus the percentage of leaf tissue that remained viable could be determined. This process was repeated using Evans Blue (0.1%) which is excluded from viable cells by the plasmalemma (Fig. 1b) (Castro-Concha *et al.* 2006). The two stains were used to provide cross verification. A dose was determined as lethal when there was less than 50% cell viability (Trevan 1927).

Uptake

Prior to any chemical analysis being undertaken, it was essential that any equipment to be used during the acid digestion process be cleaned thoroughly to remove any possible trace metal contamination (Reeve 2002). Thus all equipment was washed as described for glassware under the section on culturing.

Once samples were removed from their respective dosages they were weighed with a Mettle AC100 digital scale and dried in a Qualtex Solidstat OG18S Gravity Convection Oven at 85°C until constant weight was achieved. The

dried material was ground into a fine powder with the aid of a mortar and pestle and transferred to 50 ml plastic centrifuge tubes containing 5 ml of concentrated Aristar HCl. Samples then were incubated in a hot water bath at 80°C for 24 hours, after which they were made up to a final volume of 20 ml by the addition of double distilled water and then centrifuged in a Clements 2000 Centrifuge at a speed of 3500 rpm for 15 minutes or until a pellet was formed. The supernatant was removed and stored in sealed containers prior to metal analysis.

Analysis of arsenic concentrations in bryophytes was performed using Hydride Generation Atomic Absorption Spectrophotometry (HG-AAS) after the method outlined by Ellis and Tyson (1996). Calibration of the HG-AAS was carried out using a series of arsenic standards (0, 5, 10 and 20 μg/ml) prepared prior to analysis.

One hour prior to analysis, 5 ml of the sample was decanted into a separate container and treated with 1 ml of 10% m/v potassium iodide solution. The addition of the potassium iodide solution reduced As^{5+} to As^{3+} allowing for the maximum arsenic response to be obtained (Barra *et al.* 2000).

Analysis of arsenic content was achieved through the method referred to as 'continuous flow technique', i.e. the sample is combined with a number of other solutions (in this case HCl, a reducing agent (0.6% NaBH) and 0.5% m/v NaOH), which results in the formation of arsine gas (AsH_3). The gas is then drawn into the gas/liquid separator before being sucked into the detection cell where the absorbance of the arsenic can be calculated. In some instances the samples contained concentrations higher then could be read by the HG-AAS, so were diluted as necessary with 50% HCl.

To determine extraction efficiency, results were calibrated against those of a Standard Reference Material (SRM) 1570, spinach, with known concentrations of the five metals, and was analysed using the same protocol. This was obtained from the National Bureau of Standards (United States Department of Commerce). To determine the uptake and release of arsenic over the time course, samples were calibrated against baseline values present in *B. dichotomum* obtained prior to the exposure experiments being carried out.

Statistics

Comparisons of the uptake and viability of *B. dichotomum* collected from both sites was investigated using Analysis of Variance (ANOVA). The software package *Statistical Package for the Social Sciences* (SPSS) for windows v11 was used for these analyses. The Tukey test was applied as a *post hoc* test only where *F* values were significant. The purpose of the Tukey test is to distinguish which mean differences are significant (Fowler *et al.* 1998).

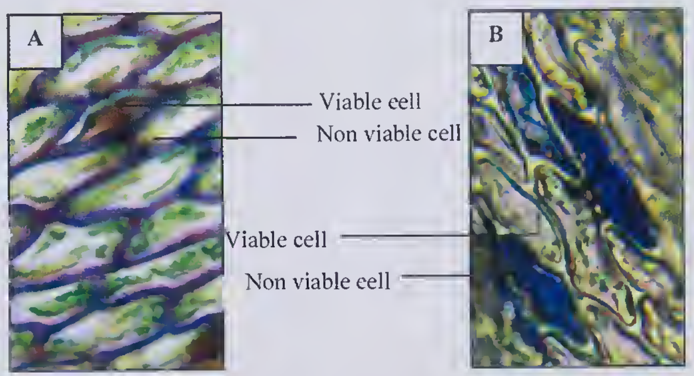

Fig. 1. Cells from leaves of *Bryum dichotomum* exposed to arsenic: A. stained with 0.1% Neutral Red. Viable cell arrowed. Neutral Red is taken up by the vacuole in viable cells B. stained with 0.1% Evans Blue. Non-viable cells arrowed. Viable cells exclude Evans Blue.

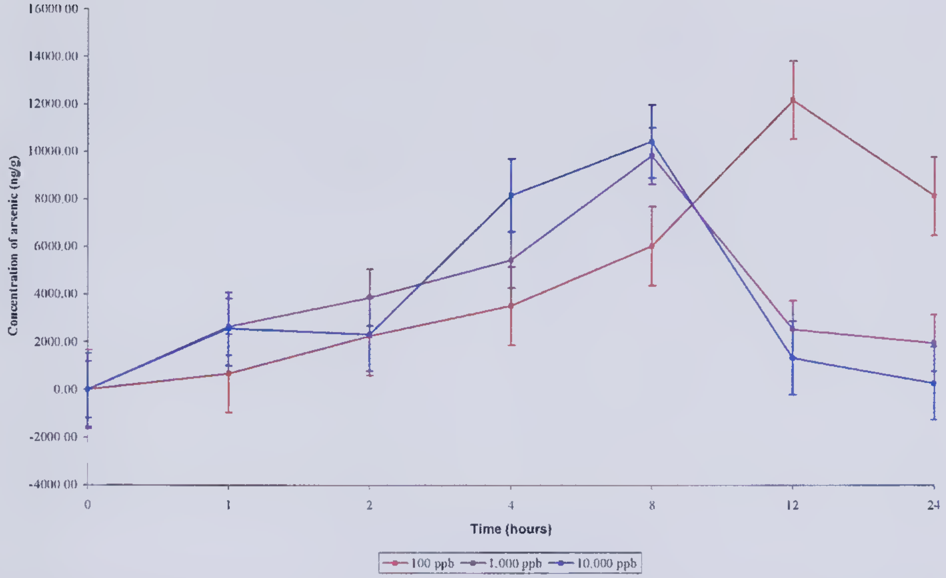

Fig. 2. Uptake of arsenic in *Bryum dichotomum* samples from Commonwealth Serum Laboratories (low arsenic) over a 24 hour exposure period.

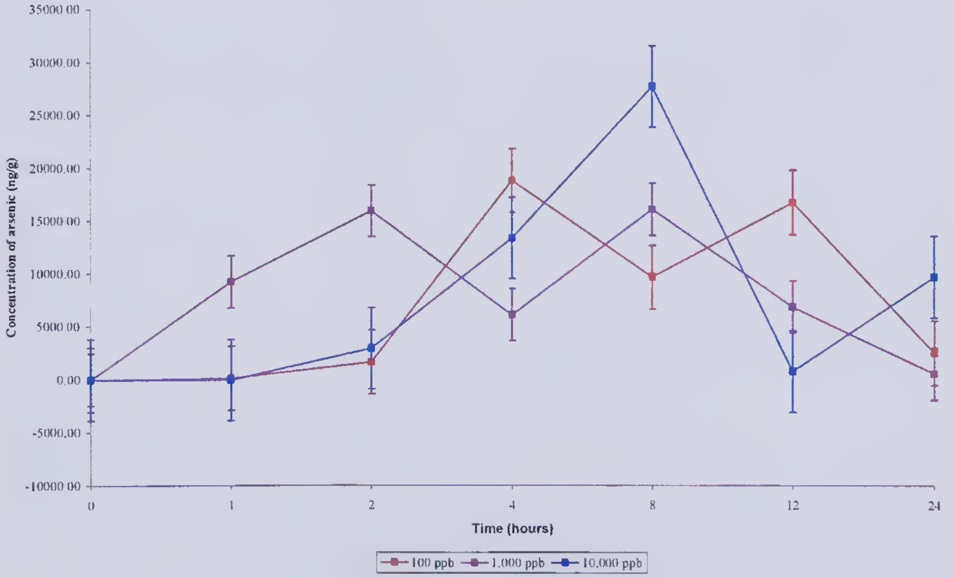

Fig. 3. Uptake of arsenic in *Bryum dichotomum* samples from Austin Hospital (high arsenic) over a 24 hour exposure period.

Results

Arsenic accumulation in *B. dichotomum* varied between the samples collected from the two areas ($F_{22,5}$ = 16.13. p<0.003) (Figs. 2 and 3). Samples from the site with high arsenic pollution (Austin) took up more arsenic than samples from the site with low pollution (CSL). Mean maximum arsenic levels reached 12, 9 and 10 µg/g at 100 ppb, 1000 ppb and 10 000 ppb exposures respectively in CSL samples and 19, 16.04 and 27.65 µg/g respectively for the same exposures in the Austin samples. This is respectively 120, 9 and 10 times the exposure concentrations for CSL samples and 190, 16 and 2.7 times for Austin samples. Within sites, there was no significant difference in uptake of arsenic between exposure concentrations for either site.

The pattern of arsenic accumulation in species was the same within sites although not synchronised with time. Samples collected from CSL (low arsenic) peaked at 8 hours when exposed to solutions of 1000 and 10 000 ppb and at 12 hours when exposed to 100 ppb (Fig. 2). After this, arsenic levels decreased. Arsenic levels in samples collected from Austin (high arsenic) fluctuated (Fig. 3).

Cell viability remained comparatively constant for control samples but decreased to about 60% viability after the 24 hours exposure to arsenic, with only minor differences occurring due to the exposure concentrations (Figs. 4 to 7). As expected, significant differences occurred between the control groups and the three dosages of arsenic within samples from both CSL (low arsenic) (Neutral Red $F_{27,3}$ = 3.561. *P* <0.02, Evans Blue $F_{27,3}$ = 3.936. *P* <0.02) and Austin (high arsenic) (Neutral Red $F_{27,3}$ = 3.219. *P* <0.04, Evans Blue $F_{27,3}$ = 2.852. *P* <0.05). Significant differences did not occur between the three dosages of arsenic for samples from either CSL or Austin.

Discussion

That a significant difference occurs in uptake of arsenic in samples of a species acclimated to different concentrations of that metal has serious implications for its use as a biomonitor. Many studies have mapped the distribution of air pollutants by determining the elemental concentrations within one, or more, species of bryophyte or lichen without first testing the uptake (and release) response/s to the pollutant/s in question. Studies have estimated deposition rates of the pollutants on the presumption that these are implicitly reflected by the elemental concentration in the biomonitor species (Wolterbeek 2003), i.e. that there is a positive correlation. Certainly there are studies that indicate this is the case (e.g. Gilbert 1968; Rühling and Tyler 1973; Steinnes *et al.* 1992) but it is not always so. The results presented in this paper clearly show that samples of *B. dichotomum* acclimated to different arsenic concentrations have different uptake responses; those acclimated to high ambient arsenic had greater uptake efficiency than those acclimated to lower ambient arsenic, i.e. when samples acclimated to high arsenic levels were placed in the same ambient arsenic as samples acclimated to low arsenic levels, the former took up significantly more arsenic than the latter. Other studies also have shown such a differential response in biomonitor performance (Briggs 1972; Brown and Buck 1978; Cai and Ma 2003; Fernández and Carballeira 2000; Shaw 1994). If the difference in biomonitor response to a pollutant correlated with the change in ambient levels of that pollutant, deposition levels would be predictable and the biomonitor could be used for mapping the distribution in concentration of that pollutant. But whether this is the case must be investigated.

Other studies have shown impacts on biomonitor-moss performance due to season, e.g. Markert and Weckert (1989) for *Polytrichum formosum*; Aceto *et al.* (2003) for *B. argenteum;* and LeBlond *et al.* (2004) for *Scleropodium purum*. Äyräs *et al.* (1997) and Bargagli *et al.* (2002) also demonstrated seasonal fluctuation of element uptake by bryophytes. Other factors also affect uptake (and release) efficiencies of biomonitors, e.g. sea salt (Berg *et al.* 1995; Berg and Steinnes 1997; Gjengedal and Steinnes 1990); acidic precipitation (Gjengedal and Steinnes 1990); variability in macro and microclimatic conditions of temperature, humidity, light and altitude (Seaward *et al.* 1988; Wolterbeek *et al.* 1996); phosphorous levels (Meharg and Macnair 1990); the concentration of the pollutant being examined (Kansanen and Venetvaara 1991); redistribution of metals

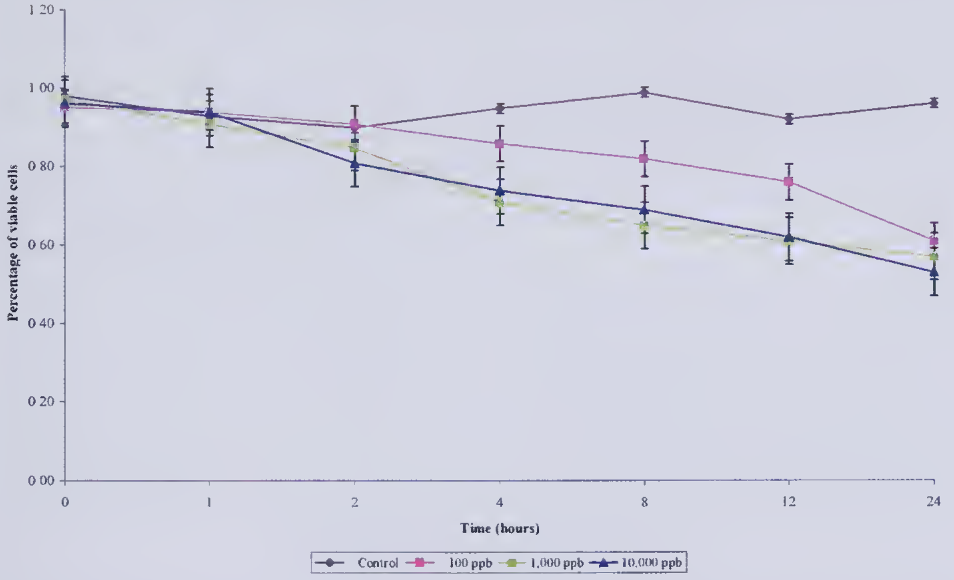

Fig. 4. Percentage of viable cells within leaves of *Bryum dichotomum* collected from CSL, a site of low arsenic pollution. Viability was determined using Neutral Red.

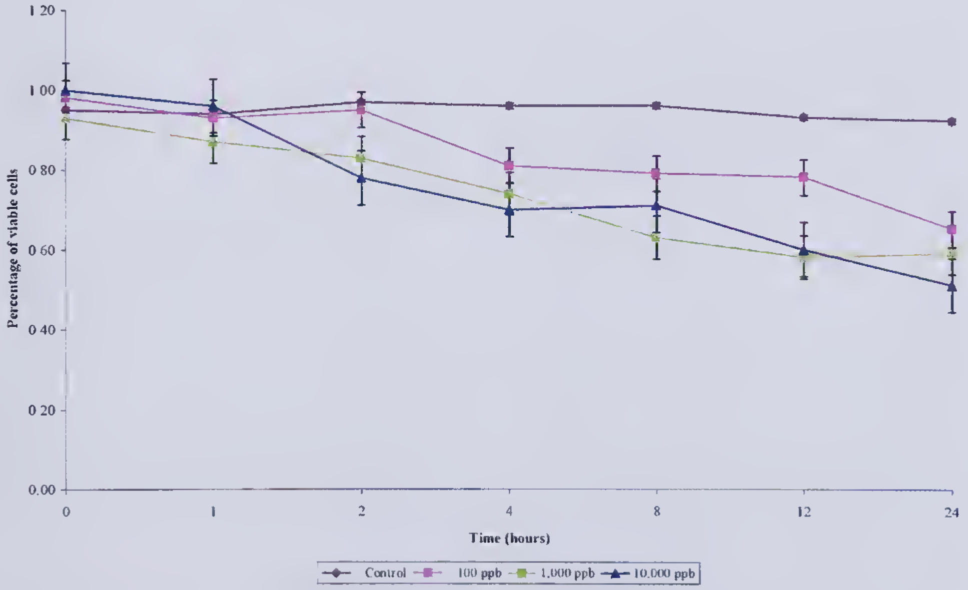

Fig. 5. Percentage of viable cells within leaves of *Bryum dichotomum* collected from CSL, a site of low arsenic pollution. Viability was determined using Evans Blue.

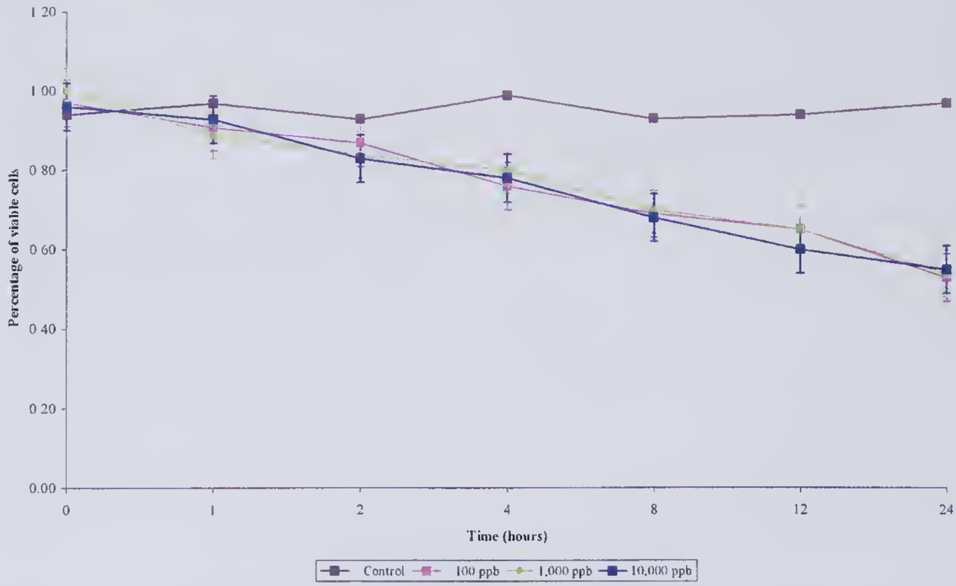

Fig. 6. Percentage of viable cells within leaves of *Bryum dichotomum* collected from Austin Hospital, a site of high arsenic pollution. Viability was determined using Neutral Red.

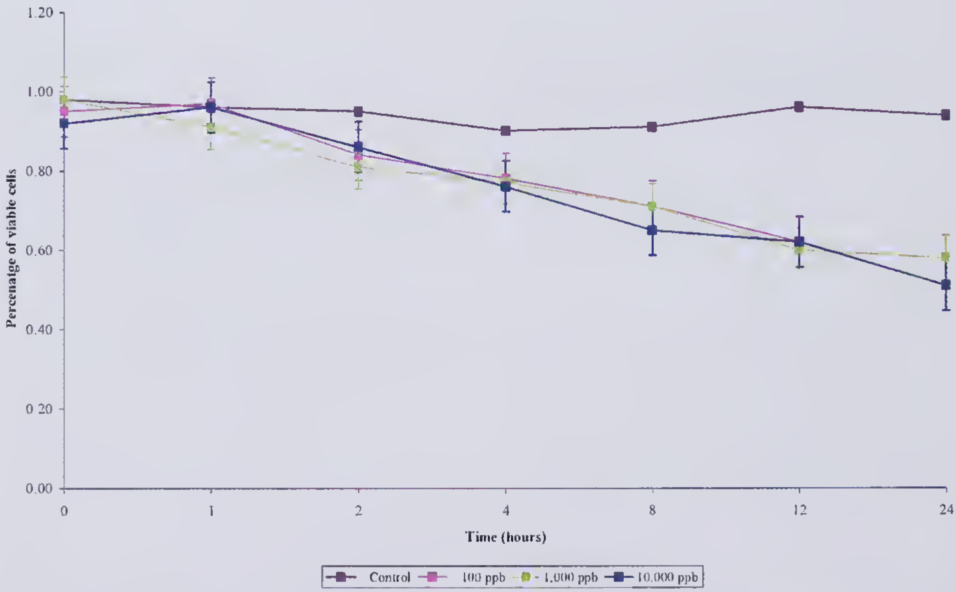

Fig. 7. Percentage of viable cells within leaves of *Bryum dichotomum* collected from Austin Hospital, a site of low arsenic pollution. Viability was determined using Evans Blue.

within a biomonitor (Brown and Wells 1990; Tyler 1990; Wells and Brown 1990); loss of metals (Sloof and Wolterbeek 1992; Taylor and Witherspoon 1972).

In consideration of the above and the results of this paper, there is a need for a combined approach in field work and laboratory analyses for pollution biomonitoring with respect to pollution mapping of actual elemental concentrations. Simple presence/absence of a pollutant can be mapped by presence of the pollutant within a biomonitor and the use of hyperaccumulators can detect habitat presence of a pollutant in minute amounts, which is important for managing potential long term effects on plant health as well as, of course, human health, but any inclusion of elemental concentrations would have to be treated with caution.

This study showed that in samples of *B. dichotomum* acclimated to low ambient arsenic, uptake rate of arsenic peaked, dropped markedly then stabilised to a low rate as indicated by the shape of the graph (Fig. 2), yet in the field this species occurs in areas with much higher concentrations of arsenic than those tested in the laboratory. Change in uptake did not match viability results, which showed a steady decrease to about 60% cell viability. Samples acclimated to the high ambient arsenic showed the same viability results over the time course of the experiment as did samples to low ambient arsenic but uptake of arsenic fluctuated. This is difficult to explain but such discrepancies in viability tests between field and laboratory data previously have been observed (Guschina and Harwood 2002; Tremper *et al.* 2004). It would have been better to have tested the arsenic levels of the incubating solution along the time series to compare with tissue solutions, but this was not done. This could have corroborated whether decrease in elemental concentration of tissue was associated with release of arsenic back into the solution. It is highly recommended that this is done in future work. It also would be useful to examine a break-down of the inter-, intra- and extra-cellular proportions of arsenic as this may affect any physiological response (Vázquez *et al.* 1999).

Concluding remarks

Variability in uptake ability of arsenic by *B. dichotomum* because of its source of origin has important ramifications for biomonitoring applications. A species hardened to a specific environment may have a very different performance response than one hardened to another environment. Similarly, one ecotype will have a different performance response from another. Unless performance response is understood for a species, it cannot be used reliably as a biomonitor to map elemental concentrations of pollutants.

References

Aceto M, Abollino O, Conca R, Malandrino M, Mentasti E and Sarzanini C (2003) The use of mosses as environmental metal pollution indicators. *Chemosphere* **50**, 333–342.

Äyräs M, Niskavaara H, Bogatyrev I, Chekushin V, Pavlov V, de Caritat P, Halleraker JH, Finne TE, Kashulina G and Reimann C (1997) Regional patterns of heavy metals (Co, Cr, Cu, Fe, Ni, Pb, V and Zn) and sulphur in terrestrial moss samples as indication of airborne pollution in a 188,000 km^2 area in northern Finland, Norway and Russia. *Journal of Geochemical Exploration* **58**, 269–281.

Bargagli R, Monaci F, Borghini F, Bravi F and Agnorelli C (2002) Mosses and lichens as biomonitors of trace metals. A comparison study of *Hypnum cupressiforme* and *Parmelia caperata* in a former mining district in Italy. *Environmental Pollution* **116**, 279–287.

Barra CM, Cervera ML, de la Guardia M and Santelli RE (2000) Atomic fluorescence determination of inorganic arsenic in soils after microwave-assisted distillation. *Analytica Chimica Acta* **407**, 155–163.

Bennett JP (2002) Algal layer ratios as indicators of air pollutant effects in *Parmelia sulcata*. *The Bryologist* **105**, 104–110.

Berg T, Røyset O and Steinnes E (1995) Moss (*Hylocomium splendens*) used as biomonitor of atmospheric trace element deposition: estimation of uptake efficiencies. *Atmospheric Environment* **29**, 353–360.

Berg T and Steinnes E (1997) Use of mosses (*Hylocomium splendens* and *Pleurozium schreberi*) as biomonitors of heavy metal deposition: from relative to absolute deposition values. *Environmental Pollution* **98**, 61–71.

Briggs D (1972) Population differentiation in *Marchantia polymorpha* L. in various lead pollution levels. *Nature* **238**, 166–167.

Brown DH and Buck GW (1978) Cation contents of acrocarpus and pleurocarpus mosses growing on a strontium-rich substratum. *Journal of Bryology* **10**, 199–209.

Brown DH and Wells JM (1990) Physiological effects of heavy metals on the moss *Rhytidiadelphus squarrosus*. *Annals of Botany* **66**, 641–647.

Cai Y and Ma LQ (2003) Metal tolerance, accumulation and detoxification in plants with emphasis on arsenic in terrestrial plants. In *Biogeochemistry of environmental important trace elements*, pp. 95–114. (Eds Y Cai and O Braids) (Oxford University Press: London)

Carbonell-Barrachina AA, Burlo F, Burgos-Hernandez A, Lopez F and Mataix J (1997) The influence of arsenic concentration on arsenic accumulation in tomato and bean plants. *Scientia Horticulturae* **71**, 167–176.

Castro-Concha LA, Escobedo RM and de Miranda-Ham ML (2006) Measurement of cell viability in: In Vitro cultures. In *Methods in molecular biology: Plant cell culture protocols*. pp 49–56. Eds VM Loyola-Vargas and F Vazquez-Flota. (Humana Press: New Jersey)

Craw D, Rufaut C, Haffert L and Paterson L (2007) Plant colonization and arsenic uptake on high arsenic mine wastes, New Zealand. *Water Air and Soil Pollution* **179**, 351–364.

Cullen WR and Reimer KJ (1989) Arsenic speciation in the environment. *Chemical Revue* **89**, 713–764.

Dahmani-Muller H, van Oort F, Gelie B and Balabane M (2000) Strategies of heavy metal uptake by three plant species growing near a metal smelter. *Environmental Pollution* **109**, 231–238.

Duan G, Zhu Y, Ting Y, Cai C, Kneer R (2005) Characterization of arsenate reductase in the extract of roots and fronds of Chinese brake fern, an arsenic hyperaccumulator. *Plant Physiology* **138**, 461–469.

Ellis RI and Tyson JF (1996) Use of a surfactant in the determination of arsenic by flow injection hydride generation atomic absorption spectrometry. *Spectrochimica Acta Part B: Atomic Spectroscopy* **51**, 1859–1866.

Fayiga AO and Ma LQ (2005) Arsenic uptake by two hyperaccumulator ferns from four arsenic contaminated soils. *Water Air and Soil Pollution* **168**, 71–89.

Fernández JA and Carballeira A (2000) Differences in the responses of native and transplanted mosses to atmospheric pollution: a possible role of selenium. *Environmental Pollution* **110**, 73–78.

Floyed AB (2010) Urban streetscape bryophytes and heavy metals: an emphasis on arsenic. (Unpublished PhD thesis, Deakin University)

Fowler J, Cohen L, Jarvis P (1998) *Practical statistics for field biology.* (John Wiley & Sons: New York)

Francesconi KA, Edmonds JS and Morita M (1994) Determination of arsenic and arsenic species in marine environmental samples. In *Arsenic in the Environment. I. Cycling and characterisation*. pp. 189–219. (Ed. JO Nriagu) (John Wiley and Sons: Canada)

Francesconi K, Visoottiviseth P, Sridokchan W and Goessler W (2002) Arsenic species in an arsenic hyperaccumulating fern, *Pityrogramma calomelanos*: a potential phytoremediator of arsenic-contaminated soils. *The Science of the Total Environment* **284**, 27–35.

Freitas MC, Reis MA, Alves LC and Wolterbeek HT (1999) Distribution in Portugal of some pollutants in the lichen *Parmelia sulcata*. *Environmental Pollution* **106**, 229–235.

Gilbert OL (1968) Bryophytes as indicators of air pollution in the Tyne Valley. *New Phytologist* **67**, 15–30.

Gjengedal E and Steinnes E (1990) Uptake of metal ions in moss from artificial precipitation. *Environmental Monitoring and Assessment* **14**, 77–87.

Guschina IA and Harwood JL (2002) Lipid metabolism in the moss *Rhytidiadelphus squarrosus* (Hedw.)Warnst. From lead-contaminated and non-contaminated populations. *Journal of Experimental Botany* **53**, 455–463.

Herzig R (1993) Multi-residue analysis with passive biomonitoring: A new approach for volatile multi-element contents, heavy metals and polycyclic aromatic hydrocarbons with lichens in Switzerland and the principality of Liechtenstein. In *Plants as biomonitors indicators for heavy metals in the terrestrial environment*. pp. 285–328. (Ed B Markert) (VCH: Weinheim)

Kansanen PH and Venetvaara J (1991) Comparison of biological collectors of airborne heavy metals near ferrochrome and steel works. *Water Air and Soil Pollution* **60**, 337–359.

Koch I, Feldmann J, Wang L, Andrews P, Reimer KL and Cullen WR (1999) Arsenic in the Meager Creek hot springs environment, British Columbia, Canada. *The Science of the Total Environment*. **236**, 101–117.

Koch I, Wang L, Ollson CA, Cullen WR and Reimer KJ (2000) Predominance of inorganic arsenic species in plants from Yellowknife, Northwest Territories, Canada. *Environmental Science and Technology* **34**, 22–26.

LeBlanc R, Rao DN and Comeau G (1972) Indices of atmospheric purity and fluoride pollution pattern in Arvida, Quebec. *Canadian Journal of Botany* **50**, 991-998.

LeBlond S, Gombert S, Colin JL, Losmo R and de Traubenberg CR (2004) Biological and temporal variations of trace element concentrations in the moss species *Scleropodium purum* (Hedw.) Limpr. *Journal of Atmospheric Chemistry* **49**, 95–110.

Lombi E, Zhao F, Fuhrmann M, Ma LQ and McGrath SP (2002) Arsenic distribution and speciation in the fronds of the hyperaccumulator *Pteris vittata*. *New Phytologist* **156**, 195–203.

Loppi S and Bonini I (2000) Lichens and mosses as biomonitors of trace elements in areas with thermal springs and fumarole activity (Mt Amiata, central Italy). *Chemosphere* **41**, 1333–1336.

Ma LQ, Komar KM, Tu C, Zhang W, Cai Y and Kennelley ED (2001) A fern that hyperaccumulates arsenic. *Nature* **409**, 579.

Macnair MR and Cumbes Q (1987) Evidence that arsenic tolerance in *Holcus lanatus* L. is caused by an altered phosphate uptake system. *New Phytologist* **107**, 387–394.

Maeda S (1994) Biotransformation of arsenic in the freshwater environment. In *Arsenic in the Environment. I. Cycling and characterisation*, pp. 155–187. Ed JO Nriagu. (John Wiley and Sons: Canada)

Markert B and Weckert V (1989) Fluctuations of element concentrations during the growing season of *Polytrichum formosum* (Hedw.). *Water, Air, and Soil Pollution* **43**, 177–189.

McArthur JM (1999) Arsenic poisoning in the Ganges delta. *Nature* **401**, 546–547.

Meharg AA (2003) Variation in arsenic accumulation - hyperaccumulation in ferns and their allies. *New Phytologist* **157**, 25–31.

Meharg AA and Hartley-Whitaker J (2002) Arsenic uptake and metabolism in arsenic resistant and nonresistant plant species. *New Phytologist* **154**, 29–43.

Meharg AA and Macnair MR (1990) An altered phosphate uptake system in arsenate-tolerant *Holcus lanatus* L. *New Phytologist* **116**, 29–35.

Meharg AA and Macnair MR (1991) Uptake, accumulation and translocation of arsenate in arsenate-tolerant and non-tolerant *Holcus lanatus* L. *New Phytologist* **117**, 225–231.

Murphy EA and Aucott M (1998) An assessment of the amounts of arsenical pesticides used historically in a geographical area. *Science of the Total Environment* **218**, 89–101.

Nieboer E, Puckett KJ, Richardson DHS, Tomassini FD, Grace B (1977) Ecological and physiochemical aspects of the accumulation of heavy metals and sulphur in lichens. In *International Conference on Heavy metals in the Environment*. Oct. *27–31, 1975, Proceedings*. Vol. 1. Part 1, pp. 331-351. Toronto, Canada.

Peryea FJ (1998) Historical use of lead arsenate insecticides, resulting soil contamination and implications for soil remediation. In *Proceedings of the 16th World Congress of soil sciences*. Montpellier, France.

Pickering DC and Puia IL (1969) Mechanism for the uptake of zinc by *Fontinalis antipyretica*. *Physiologia Plantarum* **22**, 653–661.

Raven PH, Evert RF and Eichhorn SE (1992) *Biology of plants*. (Worth Publishers: New York)

Reeve RN (2002) *Introduction to environmental analysis*. (John Wiley & Sons: England)

Reis MA, Alves LC, Freitas MC, Van Os B, de Goeij J and Wolterbeek HT (2002) Calibration of lichen transplants considering faint memory effects. *Environmental Pollution* **120**, 87–95.

Robinson B, Duwig C, Bolan N, Kannathasan M and Saravanan A (2003) Uptake of arsenic by New Zealand watercress (*Lepidium sativum*). *The Science of The Total Environment* **301**, 67–73.

Robinson B, Kim N, Machetti M, Moni C, Schroeter L, van den Dijssel C, Milne G and Clothier B (2006) Arsenic hyperaccumulation by aquatic macrophytes in the Taupo Volcanic Zone, New Zealand. *Environmental and Experimental Botany* **58**, 206–215.

Rosen BP (1999) Families of arsenic transporters. *Trends in Microbiology* **7**, 207–212.

Roychowdhury T, Tokunaga H and Ando M (2003) Survey of arsenic and other heavy metals in food composites and drinking water and estimation of dietary intake by the villagers from an arsenic-affected area of West Bengal, India. *The Science of The Total Environment* **308**, 15–35.

Roychowdhury T, Uchino T, Tokunaga H and Ando M (2002) Survey of arsenic in food composites from an arsenic-affected area of West Bengal, India. *Food and Chemical Toxicology* **40**, 1611–1621.

Rühling A and Tyler G (1973) Heavy metal deposition in Scandinavia. *Water Air and Soil Pollution* **2**, 445–455.

Salido AL, Hasty KL, Lim J-M and Butsher DJ (2003) Phytoremediation of arsenic and lead in contaminated soil using chinese brake ferns (*Pteris vittata*) and indian mustard (*Brassica juncea*). *International Journal of Phytoremediation* **5**, 89–103.

Samecka-Cymerman A and Kempers AJ (1994) Aquatic bryophytes as bioindicators of arsenic mineralization in Polish and Czech sudety mountains. *Journal of Geochemical Exploration* **51**, 291–297.

Schmoger MEV, Oven M and Grill E (2000) Detoxification of arsenic by phytochelatins in plants. *Plant Physiology* **122**, 793–802.

Seaward MRD (1995) Use and abuse of heavy metal bioassays in environmental monitoring. *The Science of the Total Environment* **176**, 129–134.

Seaward MRD, Heslop JA, Green D and Bylinska EA (1988) Recent levels of radionuclides in lichens from Southwest Poland with particular reference to 134Cs and 137Cs. *Journal of Environmental Radioactivity* **7**, 123–129.

Shahraki SA, Ahmadimoghadam A, Naseri F and Esmailzade E (2008) Study of the possibility of arsenic phytoremediation in the soil of sarcheshmeh copper complex by native plants. In *10th International Mine Water Association Congress*. Karslbad, Czech Republic.

Shaw AJ (1994) Adaptation to metals in widespread and endemic plants. *Environmental Health Perspectives* **102**, 105–108.

Sloof JE and Wolterbeek BT (1992) Lichens as biomonitors for radiocaesium following the Chernobyl accident. *Journal of Environmental Radioactivity* **16**, 229–242.

Sneller FEC, van Heerwaarden LM, Koevoets PLM, Vooijs R, Schat H and Verkleij JAC (2000) Derivatization of phytochelatins from *Silene vulgaris*, induced upon exposure to arsenate and cadmium: Comparison of derivatization with Ellman's reagent and monobromobimane. *Journal of Agricultural and Food Chemistry* **48**, 4014–4019.

Steinnes E, Rambæk JP and Hanssen JE (1992) Large scale multi-element survey of atmospheric deposition using naturally growing moss as bioindicators. *Chemosphere* **25**, 735–752.

Taylor FG and Witherspoon JP (1972) Retention of simulated fallout particles by lichens and mosses. *Health Physics* **23**, 867–869.

Tremper AH, Burton AS and Higgs DE (2004) Field and laboratory exposures of two moss species to low level metal pollution. *Journal of Atmospheric Chemistry* **49**, 111–120.

Trevan JW (1927) The error of determination of toxicity. *Proceedings of the Royal Society* **101**, 483–514.

Tyler G (1990) Bryophytes and heavy metals: a literature review. *Botanical Journal of the Linnean Society* **104**, 231–253.

Van TK, Kang Y, Fukui T, Sakurai K, Iwasaki K, Aikawa Y and Phuong NM (2006) Arsenic and heavy metal accumulation by *Athyrium yokoscense* from contaminated soils. *Soil Science and Plant Nutrition* **52**, 701–710.

Vázquez MD, Lopez J and Carballeira A (1999) Modification of the sequential elution technique for the extraction of heavy metals from bryophytes. *The Science of the Total Environment* **241**, 53–62.

Visoottiviseth P, Francesconi K and Sridokchan W (2002) The potential of Thai indigenous plant species for the phytoremediation of arsenic contaminated land. *Environmental Pollution* **118**, 453–461.

Warren GP, Alloway BJ, Lepp NW, Singh B, Bochereau FJ and Penny C (2003) Field trials to assess the uptake of arsenic by vegetables from contaminated soils and soil remediation with iron oxides. *The Science of The Total Environment* **311**, 19–33.

Wei C and Chen T (2006) Arsenic accumulation by two brake ferns growing on an arsenic mine and their potential in phytoremediation. *Chemosphere* **63**, 1048–1053.

Wells JM and Brown DH (1990) Ionic control of intracellular and extracellular Cd uptake by the moss *Rhytidiadelphus squarrosus* (Hedw.) Warnst. *New Phytologist* **116**, 541–553.

Wells JM and Richardson DHS (1985) Anion accumulation by the moss *Hylocomium splendens*: uptake and competition studies involving arsenate, selenate, selenite, phosphate, sulfate and sulfite. *New Phytologist* **101**, 571–583.

Wells B and Gilmour J (1977) Sterility in rice cultivars as influenced by MSMA rate and water management. *Agronomy Journal* **69**, 451–454.

Wolterbeek B (2003) Biomonitoring of trace element air pollution: principals, possibilities and perspectives. In *Biomonitoring of atmospheric pollution (with an emphasis on trace elements)*-BioMAP, pp. 87–104. (Atomic Energy Agency)

Wolterbeek B, Bode P and Verburg TG (1996) Assessing the quality of biomonitoring via signal-to-noise ratio analysis. *The Science of the Total Environment* **180**, 107–116.

Woolson EA, Axley JH and Kearney PC (1971) The chemistry and phytotoxicity of arsenic in soils. I. Contaminated field soils. *Soil Science Society of America Proceedings* **35**, 938–943.

World Health Organisation (2000) *Air quality guidelines*. (WHO regional office for Europe: Denmark)

World Health Organisation (2005) *The WHO recommended classification of pesticides by hazard and guidelines to classification: 2004*. (World Health Organisation: Switzerland)

Zhang W, Cai Y, Downum KR, Ma LQ (2004) Arsenic complexes in the arsenic hyperaccumulator *Pteris vittata* (Chinese brake fern). *Journal of Chromatography A* **1043**, 249–254.

Zhang W, Cai Y, Tu C and Ma LQ (2002) Arsenic speciation and distribution in an arsenic hyperaccumulating plant. *The Science of the Total Environment* **300**, 167–177.

Zhao F, Dunham SJ and McGrath SP (2002) Rapid report Arsenic hyperaccumulation by different fern species. New-species. *New Phytologist* **156**, 27–31.

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'A correspondence long interrupted': Ronald Gunn re-establishes contact with Joseph Hooker in 1870

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Abstract

Ronald Campbell Gunn was one of the foremost Australian plant collectors who sent specimens to William and Joseph Hooker during the first half of the nineteenth century, until he abruptly broke off all correspondence. In a letter sent to Joseph Hooker two decades later, in 1870, Gunn reveals the reasons for this hiatus, and sends specimens of Tasmanian *Acacia* species and of a New Zealand plant now known as *Phormium cookianum* subsp. *hookeri* (Gunn ex Hook. f.). Remarks in the letter on these specimens reveal a controversy with Ferdinand Mueller on definition of species, and allow correction of the erroneous locality for the *Phormium* later published by Hooker. (*The Victorian Naturalist* 131(6), 2014, 204-208)

Keywords: biography, collectors, Ferdinand von Mueller, taxonomy, *Phormium cookianum* subsp. *hookeri*

Introduction

Ronald Campbell Gunn (1808-1881) was a prominent figure in early Tasmania, holding many important public appointments, is now better known for his contributions to Australian botany (Blackwood 2012); he sent many specimens to Sir William Hooker (1785-1865) before and after his 1841 appointment as director of the Royal Botanic Gardens at Kew, England, and to his son and successor Dr Joseph Dalton Hooker (1817-1911). Much of his correspondence with Sir William has been published (Burns and Skemp 1961), and selected extracts from the correspondence with Dr Hooker are also on record (Burns and Skemp 1961; Endersby 2001, 2011).

Botanical communications from Gunn to the Hookers are regarded as having ceased abruptly in 1849 or thereabouts (Burns and Skemp 1961), although Endersby (2001) gives a date of 'about 1860', and there have been speculations about the cause of this. Endersby (2001, p. 349; 2008) put forward the following:

> His growing prosperity seems to have coincided with a gradual loss of interest in botany. Perhaps managing his estates became too time-consuming. But perhaps he felt that, because he had finally become a gentleman, he no longer needed to engage in aspirational, gentlemanly pursuits.

While studying the nomenclature of New Zealand Flax (genus *Phormium*), I became aware that Gunn had sent a specimen to Joseph Hooker in 1870. When a copy of the covering letter (Gunn 1870) was obtained from the Kew Gardens archives, it became apparent that it was of much wider interest than the reason for which I requested it.

The honorifics used in this paper reflect the subjects' titles in 1870, before Joseph Hooker became Sir Joseph and Ferdinand Mueller became Baron von Mueller.

Background

Ronald Campbell Gunn first became interested in botany when assistant superintendant of convicts at Launceston, Tasmania, in the 1830s. His friend Robert Lawrence was already one of Sir William Hooker's collectors, and Gunn soon became a collector himself (Endersby 2001). After holding various positions in the judicial system, he became private secretary to the Lieutenant-Governor, Sir John Franklin, in 1840, and accompanied Sir John and his wife on several expeditions (Blackwood 2012). Also in 1840, Joseph Hooker arrived in Hobart with the Ross Antarctic Expedition; the two men became firm friends and went on collecting expeditions for specimens which were eventually used in Hooker's (1860) *Flora Tasmaniae* along with material sent to Kew by Gunn (Endersby 2001).

Gunn left the public service in 1841 and became manager of the rich Lawrence and Franklin estates. This enabled him to form the first scientific society in Australasia, eventually known as the Tasmanian Society, and publish the *Tasmanian Journal of Natural Science* to

which he contributed many papers. In 1848, however, his society was subsumed by the Royal Society of Van Diemen's Land (later, of Tasmania) and the Royal Society's *Papers and Proceedings* soon superseded the *Journal*. Gunn became a member of the Royal Society at its first meeting in 1848 (Milligan 1850) and published papers in its journal.

He was elected to the upper house of Parliament in 1855, and later to the House of Assembly, but resigned in 1860. He rejoined the public service and held numerous positions which are listed elsewhere (see Burns and Skemp 1966). One notable appointment relevant to this paper was as the Tasmanian representative on a New Zealand commission to decide a new capital for that colony.

Until 1865, the capital of New Zealand was Auckland, but agitation grew for a more central location; several towns put themselves forward, and to avoid any suspicion of favouritism, Parliament resolved to form a commission of representatives from the Australian colonies of New South Wales, Victoria and Tasmania to decide the matter (Bagnall 1985). Gunn was nominated by the Tasmanian Governor, Col. Gore-Browne. Gunn and the other commissioners arrived in New Zealand in July 1864, and issued their report in October that year, recommending Wellington become the capital, which came to pass the following year.

Discussion

The long interruption

The letter from Gunn to Hooker which renewed the correspondence (Appendix 1) suggests quite a different explanation for the hiatus in letters to Hooker from those put forward by Endersby. Far from enjoying prosperity, Gunn was experiencing ill-health and financial hardship on top of deaths of his children. All these are triggers for depression. And indeed, neglecting his correspondence demonstrates two of the overt symptoms of depression: withdrawal from contact and loss of interest in previously enjoyable things (see, for example, the website http://www.beyondblue.org.au/the-facts/depression/signs-and-symptoms, accessed 5/11/2013).

When Gunn was elected to the Tasmanian Parliament he seems to have been more conspicuous by his absences than by his contributions (Baulch 1961). Certainly, the letter makes it clear that his leaving Parliament and rejoining the public service was forced on him by circumstances. As can be seen from the biographical details above he certainly was not idle in the period 1849 to 1870 although his letter to Hooker suggests a level of depression which perhaps he kept from those around him.

The two Acacias

Gunn's characterisation of Ferdinand Mueller as a 'chamber botanist' seems unnecessarily harsh. Mueller had been an active explorer and plant collector in his youth, but by 1870 he had held a responsible position as Government Botanist for Victoria for nearly 20 years, and was producing a huge volume of published botanical work including the monumental *Flora Australiensis* in collaboration with Hooker's elder colleague at Kew, George Bentham (Home *et al.* 2002; Lucas 2003). Since 1862 his employment had been under increasing attacks which were eventually to culminate in his dismissal in 1873 (Home *et al.* 2002).

The two men kept up a correspondence throughout the period when Gunn stopped writing to the Hookers, even though they had their differences. Mueller, for example, was at that time an opponent of Darwin's theory of evolution (Home *et al.* 2002) and agreed to disagree with Gunn on such matters as fixity of species (Mueller to Gunn 6th January 1865, in Home *et al.* 2002).

Gunn's example of Mueller's conflation of distinct species is rather puzzling. The names *Acacia mollissima* (Black Wattle, currently accepted name: *A. mearnsii*) and *A. dealbata* (Silver Wattle) had been used by Hooker in his *Flora Tasmaniae* (Hooker 1860, p. 111), with the remark that the first species was,

> very similar indeed to the *A. dealbata*, and probably only a state of that plant, though looking very different when seen beside it.

The second volume of the *Flora Australiensis*, issued in 1864, placed *A. mollissima* in synonymy with *A. decurrens* or one of its varieties. As for *A. dealbata*, Bentham wrote that it 'is unhesitatingly united with *A. decurrens* by F. Mueller. J.D. Hooker considers it as sufficiently distinct, although not easy to characterize from dried specimens.' (Bentham and Mueller 1864).

But it was still listed as a separate species, with Hooker's opinion (probably communicated verbally to Bentham) overriding Mueller's.

Gunn does not seem to have been satisfied with this outcome. Perhaps he had seen something in the draft of Mueller's second volume of *Indigenous Plants of Victoria* (this volume was never published: Home *et al.* 2002). Mueller wrote to Gunn on 12 June 1867, apparently in reply to a letter from Gunn which has not survived (Home *et al.* 2002: 417-418):

> 'Acacia mollissima & A dealbata grow both here on one ridge. The difference in flowering time, which I noted for many years, arises from the very difference of locality ... My seed collector in the Garden will be asked tomorrow about the ripening of Acacia mollissima & dealbata, both common on the Yarra.'

Unfortunately the seed collector's response is not in any surviving letter either.

The question of the two acacia species had been settled in the definitive *Flora Australiensis* probably by Hooker himself, and why Gunn chose to mention Mueller's opinion is a mystery. His inclusion of details of the seeding period of the Black Wattle is also superfluous; he had previously said exactly the same in a paper on *Acacia* many years before (Gunn 1846). Hooker (1860) had cited this paper as a useful reference on the genus and would presumably remember its contents, yet Gunn's letter reads as if this characteristic of the wattle is some new item of information hitherto unknown to Hooker. Some explanation in the psychological realm must again be considered, perhaps to do with the stress of writing the preceding paragraph.

Phormium hookeri

From a purely botanical viewpoint, the most important part of the letter deals with the 'new *Phormium*' specimens which were enclosed. As stated by Hooker (1888), it was from Gunn's visit to New Zealand in 1864 as a member of the Seat of Government commission that these originate.

After arriving first at Auckland, the commission went to Wellington on a steamer which stopped at Napier for a couple of hours. Here Gunn met his New Zealand botanical counterpart, William Colenso, for the first and only time (Bagnall 1985). Colenso later mentioned the visit to Hooker, adding

> I learnt from him he had a copy of your Zoology

(Colenso to Hooker 30th November 1864, in St. George 2009: 311). As Hooker had not written any works on zoology, this remark is rather puzzling.

The commission proceeded to inspect the candidate locations by chartered steamer. Although most of the places that had put themselves forward for consideration were in the vicinity of Cook Strait, the more distant Whanganui area had also asked to be included.

The commission arrived at Whanganui on about 21 August 1864. The navigable Whanganui River was considered by the inhabitants as one of the township's natural advantages. However, some of the Māori inhabitants of the area had become members of a militant anti-Government religious cult, the Pai Mārire, who practised decapitation of their enemies, and the river formed as much a highway for them as for Government forces. In May that year, an attempt by a Pai Mārire war party to pass down the river had been blocked by local Māori at the Battle of Moutoa in which 66 lives were lost. The commission decided to investigate the situation for themselves. They first made a short trip up the river by steamer, then one or two days later Gunn and one other member went further upstream by canoe to witness a re-enactment of the battle (Bagnall 1985). Presumably it was on this second expedition that Gunn gathered plants of *Phormium* which he took back to Launceston. It is worth emphasising that this journey was by primitive transport up a river in flood, in winter weather, into an area still teeming with insurgents; the less adventurous Victorian member of the commission chose to abandon his colleagues and head for a safer part of the country (Bagnall 1985).

The specimen which Gunn sent to Hooker in 1870 consists of the top of the inflorescence, with six side branches, each bearing a number of mature capsules. A packet attached to the herbarium sheet contains loose seeds (http://apps.kew.org/herbcat/getImage.do?imageBarcode=K000644300, accessed 5/11/2013). The specimen is accompanied by a note in Gunn's handwriting:

Phormium Hookeri. Gunn 1864. 30 to 40 miles up Wanganui River, New Zealand. Growing abundantly in fissures of almost perpendicular cliffs - Habit form very different from P. tenax - plants hanging downwards - Native name Tiwai Kapu. Found by Ronald C. Gunn in 1864. Plants taken to Tasmania where it flowers well.

The last sentence indicates the note was written in 1870, not 1864, and thus it is more likely than not that the specimen is from Gunn's garden. In another hand is written: 'From Ron. Gunn 9/70'.

Hooker did not use the specimen which Gunn had sent, but he did add it to the Kew herbarium. Many years later Hooker observed similar plants, grown from seed sent from the Whanganui district, in his brother-in-law's garden at Torquay, England, and with these live specimens available decided to publish a new species which, remembering Gunn's request, he called *Phormium hookeri* Gunn, citing the note (Hooker, 1888). The plant is now known as *Phormium cookianum* Le Jol. subsp. *hookeri* (Gunn ex Hook. f.) Wardle (1979).

However, in the published description, Hooker stated 'the locality in which Mr. Gunn found it was the Waitangi river'. This is evidently a typographic error; it is not the only one, as the genus *Phormium* is ascribed to a non-existent author 'Font.' rather than to 'Forst.'. The erroneous locality has been maintained by later researchers such as Wardle (1979).

Aftermath

Whether Gunn's letter was the start of any further correspondence will be left to future researchers. Burns and Skemp (1961) have suggested that if there were any later letters they may have lacked significant botanical content and were therefore placed among Hooker's personal letters rather than in the Kew archives. Gunn certainly corresponded with other European botanists in this late period; a letter from JG Agardh to Mueller in 1872 (Home *et al.* 2002) mentions that Gunn had sent him a collection of Tasmanian algae.

Gunn's rheumatism worsened. By 1876 he was unable to write so much as his own name (Burns and Skemp 1966), and retired from the public service. It became so bad that for the last two years of his life he was unable even to move unassisted (Baulch 1961).

In his obituary of Gunn, Hooker (1882) mentioned Gunn's visit to New Zealand and that his 'health broke down under the close confinement and long hours of office work at Hobarton', but this and many other details seem to have been merely copied from a newspaper obituary (e.g. *Launceston Examiner* of 14 March 1881 which has the same wording in many places).

This letter gives a first-hand glimpse into Ronald Campbell Gunn's later life, with a subjective view that is altogether missing from the rather dry biographies (Baulch 1961; Burns and Skemp 1966; Buchanan 1990).

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References

Bagnall AG (1985) The Seat of Government Commission, 1864: an Australian intervention. *Turnbull Library Record* **18**, 5–21.

Baulch W (1961) Ronald Campbell Gunn. In Burns and Skemp (1961), pp. xiii–xix.

Bentham G and Mueller F (1864) *Flora Australiensis. Vol. II. Leguminosae to Combretaceae.* (Lovell Reeve: London)

Blackwood L (2012) The contribution of Ronald Campbell Gunn to our knowledge of the flora and fauna of Tasmania. *La Trobeana* **11** (3), 30–36.

Buchanan A (1990) Ronald Campbell Gunn (1808-1881). In *A history of systematic botany in Australasia: proceedings of a symposium held at the University of Melbourne, 25-27 May 1988*, pp. 179–192. Ed P Short. (Australian Systematic Botany Society: South Yarra)

Burns T and Skemp J (eds) (1961) *Van Diemen's Land correspondents: letters from R.C. Gunn, R.W. Lawrence, Jorgen Jorgenson, Sir John Franklin and others to Sir William J. Hooker, 1827–1849.* (Queen Victoria Museum: Launceston).

Burns T and Skemp J (1966) Ronald Campbell Gunn. In *Australian Dictionary of Biography. Vol. 1: 1788–1850 A-H*, pp. 492–493. (Melbourne University Press: Carlton)

Endersby J (2001) 'From having no herbarium.' Local knowledge versus Metropolitan Expertise: Joseph Hooker's Australasian Correspondence with William Colenso and Ronald Gunn. *Pacific Science* **55**, 343–358.

Endersby J (2008) *Imperial Nature: Joseph Hooker and the practices of Victorian Science.* (Chicago University Press: Chicago)

Endersby J (2011) A life more ordinary: the dull life but interesting times of Joseph Dalton Hooker. *Journal of the History of Biology* **44**, 611–631.

Gunn RC (1846) Notes on the *Acaciae* of Tasmania. *Tasmanian Journal of Natural Science* **3**, 5-17.

Gunn RC (1870) Letter to J.D. Hooker, 2 May 1870. Directors' Correspondence vol. 172 f. 234. (Unpublished: Royal Botanic Gardens Kew Archives)

Home RW, Lucas AM, Maroske S, Sinkora DM and Voigt JH (eds) (2002). *Regardfully yours: selected correspondence of Ferdinand von Mueller, vol. 2: 1860–1875.* (Peter Lang: Bern)

Hooker JD (1860) *The botany of the Antarctic voyage of H.M. discovery ships Erebus and Terror in the years 1839-1843 : under the command of Captain Sir James Clark Ross. Part III. Flora Tasmaniae. Vol. I. Dicotyledons.* (Lovell Reeve: London)

Hooker JD (1882) [Obituary:] Ronald Campbell Gunn. *Proceedings of the Royal Society of London* **34**, xiii-xv.

Hooker JD (1888) *Phormium hookeri. Curtis's Botanical Magazine* **114**, t. 6973.

Lucas AM (2003) Assistance at a distance: George Bentham, Ferdinand von Mueller and the production of *Flora australiensis. Archives of Natural History* **30**, 255–281.

Milligan J (1850) Proceedings. *Papers and Proceedings of the Royal Society of Van Diemen's Land* **1**, 154–178.

St George IM (ed) (2009) *Colenso's collections including the unpublished work of the late Bruce Hamlin on William Colenso's New Zealand plants held at Te Papa.* (New Zealand Native Orchid Group: Wellington)

Wardle P (1979) Variation in *Phormium cookianum* (Agavaceae). *New Zealand Journal of Botany* **17**, 189–196.

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Appendix 1. The letter of RC Gunn to W Hooker

Launceston Tasmania,
2nd May 1870.

My dear Hooker,

I take the opportunity of my son John Jamieson Gunn going to England to study medicine to resume a correspondence long interrupted, from various causes, on my part, by commending him to your tender care as a stranger in a strange land, and to say that any kindness you can show him will be gratefully appreciated by me.

Domestic affliction in the loss of child after child at all ages up to 28. Heavy pecuniary losses, (some £20,000.) and subsequently broken health – made me shirk all correspondence. I had to re-enter the Govt. Service, and again become a drudge – worse off in 1870 than I was in 1840! Rheumatism has now crippled my right arm so that I write with difficulty. All these are apologies which you must take for what they are worth.

My friend Mr Mueller of Melbourne is knocking down all the old specific landmarks – the effect of being what I call a chamber botanist working in many cases with a limited number of specimens. And furnishing work for future laborers to restore nine tenths to their old places and stations! A field botanist would draw different conclusions. e.g. Acacia dealbata & A. mollissima, of which I now send you specimens. One flowers in August & ripens its fruit in Dec; - the other flowers in Dec - & ripens its fruit the year after – that is it takes 13 months!! This peculiarity of taking over a year applies to some other (Australian) sp. although I do not think Mueller notices it.

I send you specimens of a new Phormium found by me growing in fissures of nearly perpendicular cliffs up the Wanganui River, N.Z., some 30 or 40 miles. It is not P. Colensoi I imagine. Leaves not erect, but like large plants of Hemerocallis flava. Spikes of flowers hang downwards, and fruit is pendulous. It is a beautiful small species now thriving in my garden. If new pray call it at my request P. Hookeri. The fibre is very tough. Maori name is "Tiwai Kapu" and they told me it was very superior to & more valued than the common flax, which grew below it on the margin of the river. Let me know if there is anything you specially want – as I shall try to send it.

Believe me always

Most sincerely yours
Ronald C Gunn

Victoria's rainforests and the potential impacts of a changing climate

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Abstract

Though once prolific across the continent, the rainforests of Australia have receded to a fraction of their original extent. In Victoria, rainforests account for as little as 0.14% of the state, and a disproportionately large number of species are found within them. As rainforests are found where temperatures are mild and rainfall is consistent and high, the prospect of a changing climate threatens their structure, function, and possibly their existence. This desktop study investigated climate predictions based on various emissions scenarios, and compared them to current characteristics and requirements of Victoria's cool temperate rainforests to determine the impact they could have on these forests, particularly the most iconic species found within them, such as *Atherosperma moschatum* Labill. c Labill. and *Nothofagus cunninghamii* (Hook.) Oerst, which may be most at risk to the effects of climate change, particularly fire. The study explores the impact a changing climate may have on the rainforests of Victoria and focuses on some key canopy species of cool temperate rainforest. It also brings into light the need for more research into climate change in conjunction with other key ecosystem factors such as soil type, elevation and human disturbance. (*The Victorian Naturalist* **131**(6), 2014, 209-218)

Key words: Climate change, cool temperate rainforest, *Nothofagus cunninghamii*, *Atherosperma moschatum*

Introduction

The roots of today's rainforests have been traced back to when Australia was part of the Gondwanan super-continent (100 mya) (Peel 1999). At that time, most of Australia was covered by rainforest. Since then, however, the distribution and dominance of rainforest has varied as Australia broke free of the super-continent and underwent numerous climatic changes (Beadle 1981). It is thought that the Australian continent moved 30° of latitude north during the Cretaceous and Tertiary, causing significant climatic changes (Beadle 1981). The ancient climatic regime to which rainforests were adapted, i.e. dependable, high rainfall and low fire frequency, is now rare and Australia's rainforests have receded to isolated, protected patches (Peel 1999).

Rainforests can be defined according to rainfall, atmospheric conditions, soil and local topography. For the purpose of this article, a rainforest is characterised by a closed tree canopy that distinguishes it from other vegetation in areas of high rainfall, generally comprises many taxa and, perhaps most significantly, has canopy species with the ability to regenerate without the need for broad-scale disturbance (Busby and Brown 1994).

Five main types of rainforest occur in Victoria. Cool temperate rainforest occurs in the Otway Ranges, Wilsons Promontory, the Strzelecki Ranges, the Central Highlands and some parts of East Gippsland (Peel 1999). At lower elevations, the gradient from cool temperate rainforest to tall eucalypt forest includes a 'mixed' ecotone of cool temperate mixed forest. This blurred boundary from one vegetation type to another is unique in itself; it is characterised by an understorey of rainforest species with a eucalypt canopy (Busby and Brown 1994). Warm temperate rainforests are floristically rich and are most common east of the Mitchell River in East Gippsland, although other communities may be found in the Strzeleckis and at Wilsons Promontory (Peel 1999). Gallery rainforest is found in river valleys of East Gippsland, and dry rainforest, the least common of the five Victorian rainforest types, is found only in areas east of the Mitchell River and, due to its habitat, is relatively removed from fire danger (Peel 1999).

Rainforests occur as far west as Cape Otway and reach into the far corners of East Gippsland. They occupy less than 0.14% of Victoria, yet a disproportionate number of rare or threatened species may be found within them (Peel 1999).

They have high levels of biodiversity, are valued for their water provision and are becoming increasingly more important for carbon capture and storage (Lindenmayer *et al.* 2011; Mackey *et al.* 2008). With this knowledge, it makes the need to protect them an even greater priority; however, climate change is a looming threat to the viability of rainforests in the future.

The distribution, health and abundance of Australian vegetation depend on consistencies in temperature, rainfall, fire regime and soil fertility as well as other factors (Beadle 1981). It is predicted that climate change will significantly alter three of these four parameters. Temperatures are predicted to continue to rise, annual rainfall will decrease and extreme weather events such as fire will increase in frequency and intensity (VCC 2008). Victoria's rainforests are particularly sensitive to such changes in the environment; key rainforest species such as *Atherosperma moschatum* Labill. c Labill. have low photosynthetic tolerance in high temperatures (Read and Busby 1990). Fire and climate are strongly correlated with the geographical limits of the prominent rainforest canopy species *Nothofagus cunninghamii* (Hook.) Oerst (Busby 1986). What will become of Victoria's rainforests?

In 2008, the Victorian Government released a summary of climate change predictions for Victoria prepared by CSIRO. This summary predicts that Victoria will become warmer and drier in the near future as a result of climate change. Victoria will experience more rapid warming than global trends, with a predicted temperature increase of 0.8°C per annum by 2030 (VCC 2008). The number of hot days will increase in frequency and intensity, more so in inland regions than coastal regions (VCC 2008a). Annual rainfall is expected to decrease by 4% by 2030 and 6% by 2070 (VCC 2008). Not only will the state become drier, but drought risk will increase by 10–80% by 2070 due to enhanced evaporation (VCC 2008a). Perhaps most threatening to Victoria's rainforests will be the predicted increase in fire frequency and intensity due to climate change. The warmer, drier climate will result in a greater number of 'extreme' fire danger days. By 2020, the number of 'extreme' fire days is estimated to increase by 5–40%, relative to the climate of 1974 to 2003 (VCC 2008). Under a low-emissions scenario, by 2050, the number of fire days may increase from 15–25% but under a higher-emissions scenario the risk of extreme fire danger days may increase by a staggering 120–230% (VCC 2008). This is grim news for Victoria, and especially for its unique rainforests. Some areas will be more at risk than others; for instance with the varying predictions for coastal versus inland sites, the rainforest of the Otways may be less affected than the rainforest of the Central Highlands.

The effect of climate change on the rainforests of Victoria

The summary of predictions for climate change in Victoria divides the state into ten main regions (VCC 2008). Climate change will affect different parts of the state to different degrees and in varying ways. The five different rainforest types found across the state have different requirements and tolerances for rainfall, fire frequency and temperatures. Therefore, the impacts of climate change on Victoria's rainforests will vary not only according to the specific requirements of the rainforest type itself, but also with regard to its locations throughout the state.

Each rainforest type found in Victoria will experience raised temperatures and reduced rainfall by 2030 and 2070 compared to current levels; while cool temperate rainforest is found in more regions than any other rainforest type, curiously, it has more restricting climate limitations than other rainforest types. This means that changes in climate will significantly affect cool temperate rainforests. By 2030, cool temperate rainforests across the state may experience temperature increases averaging 0.8°C per year; and 3.6% less rainfall than current levels. The higher emission scenario for 2070 could see temperature rises in areas of cool temperate rainforests as high as 2.6°C per annum; and 10.6% less rainfall than present-day levels (Table 1).

To compare the effect climate change will have on temperatures and rainfall levels in the near future with regard to the rainforests of Victoria, the differences between current levels and predicted levels are expressed in percentage form in Table 2. In 2070, gallery and dry rainforests

Table 1. Current and predicted future temperatures and annual rainfall in Victoria's rainforests (after Peel, 1999; VCC 2011a; VCC 2011b; VCC 2011c; VCC 2011d; VCC 2011e).

Rainforest Type	Locations	Current Temps Winter/Summer*	2030 Temps	2070 Temps - Lower/higher emissions	Current rainfall (mm)	2030 rainfall	2070 rainfall
Cool Temperate		**0-6°C/6-12°C**			**1200-2000mm**		
	North East	1.4°C/11.2°C	+0.9°C	+1.5°/2.9°C	1089mm	-3%	-5%/-10%
	Otways	5°C/11.6°C	+0.8°C	+1.3°C/2.4°C	773mm	-4%	-6%/-12%
	Wilson's Promontory	4°C/11.5°C	+0.8°C	+1.4°C/2.6°C	926mm	-4%	-6%/-11%
	Strzeleckis	4°C/11.5°C	+0.8°C	+1.4°C/2.6°C	926mm	-4%	-6%/-11%
	Central Highlands	4.6°C/12°C	+0.8°C	+1.3°C/2.6°C	864mm	-4%	-6%/-11%
	East Gippsland	2.3°C/11.1°C	+0.8°C	+1.4°C/2.7°C	924mm	-3%	-5%/-9%
Cool Temperate		**0-6°C/6-12°C**			**1200 - 2000mm**		
Mixed Forest	Central Highlands	4.6°C/12°C	+0.8°C	+1.3°C/2.6°C	864mm	-4%	-6%/-11%
	East Gippsland	2.3°C/11.1°C	+0.8°C	+1.4°C/2.7°C	924mm	-3%	-5%/-9%
Warm Temperate		**4.8°C/14.1°C**			**734-1200mm**		
	Strzeleckis	4°C/11.5°C	+0.8°C	+1.4°C/2.6°C	864mm	-4%	-6%/-11%
	East Gippsland	2.3°C/11.1°C	+0.8°C	+1.4°C/2.7°C	924mm	-3%	-5%/-9%
Gallery Rainforest		**4.8°C/14.1°C**			**734-1200mm**		
	East Gippsland	2.3°C/11.1°C	+ 0.8°C	+1.4°C/2.7°C	924mm	-3%	-5%/-9%
	Dry Rainforest	1.9°C/14.5°C			716-994mm		
	East Gippsland	2.3°C/11.1°C	+0.8°C	+1.4°C/2.7°C	924mm	-3%	-5%/-9%

Table 2. The percentage differences in average temperatures and annual rainfall across Victoria's rainforest types according to lower emissions scenarios for 2030 and 2070 for the state of Victoria.

	Average Temperature Increase by %				**Average difference in annual rainfall by %**
	2030		2070		2070
Rainforest type	Winter	Summer	Winter	Summer	Lower emissions
Cool temperate rainforest	23	7	39-74	12-23	-28
Cool temperate mixed forest	23	7	39-74	12-23	-30
Warm temperate rainforest	25	7	44-86	12-24	14
Gallery rainforest	35	7	61-117	13-21	20
Dry rainforest	35	7	61-117	13-21	23

may experience winter temperature increases of 61% above current temperatures under a lower emissions scenario whereby CO^2 emissions increase until 2040, at which point they decline (VCC 2008). This is the minimum increase we can expect in 2070. Other rainforest types will experience an increase of about 40–44%. In summer, all rainforest types will experience a 12–13% temperature rise from current-day levels (Table 2).

Rainforests are characterised by fairly dependable temperature and rainfall thresholds. Cool temperate rainforests and cool temperate mixed forests currently require high to very high annual rainfall of 1200–2000 mm (Peel 1999). Warm temperate, dry and gallery rainforests require moderate to high levels of annual rainfall of 716–1200 mm (Peel 1999). Based on lower emissions scenario predictions for 2070, dry, gallery and warm temperate rainforest will be sitting well within the thresholds of their annual rainfall requirements (Fig. 1). Cool temperate rainforest and cool temperate mixed forest, on the other hand, will receive between 28 and 30% (on average) less than their minimum annual rainfall requirement (Fig. 1).

Changing fire regimes

Dry rainforest resists fire due to its location, while the proximity to fire-shielding landscape elements like estuaries or lakes often protects warm temperate rainforests from fire (Peel 1999). Unlike dry and warm temperate rainforest, the fire resistance of cool temperate rainforest is dependent on impermanent defences such as temperature and moisture levels, which make them the most vulnerable to climate change. Cool temperate rainforests form a closed canopy after long periods without disturbance, which then serves to foster a humid interior that not only keeps the forest moist, but also aids in the rapid decomposition of fine fuels (Busby and Brown 1994). Should rainfall levels fall and temperatures rise, this protective humidity eventually will decline, fuel loads will increase and any lichen-covered stags that stand in the forest will dry out, making them a flammable opening in the canopy (Busby and Brown 1994). As rainforests are characterised by long periods without fire, and since it appears that the cool temperate rainforests of Victoria will be most at risk of fire in the not-too-distant future, the potential effects of climate change on cool temperate rainforests are further examined here.

Cool temperate rainforest occurs in areas where fire-free intervals are greater than 400 years (Peel 1999), but with the risk of fire in Victoria predicted to increase by 15–70% in 2050, such long intervals may become a thing of the past (Table 3). Indeed, fire frequency in the Central Highlands of Victoria is already higher than that of the last century (Lindenmayer *et al.* 2011), and one of the largest areas of cool temperate rainforest and cool temperate mixed forest occurs in this region.

Should fire threaten areas in which cool temperate rainforests occur, it is predicted that a positive feedback system will begin wherein with each fire comes greater risk of more fire until, eventually, what we now define as cool temperate rainforest in these key areas will become sclerophyll forest. Once the normally-closed canopy of a cool temperate rainforest is penetrated by fire, it is recolonised by more fire-prone and also more fire-tolerant species such as *Acacia* and *Eucalyptus*. This is known

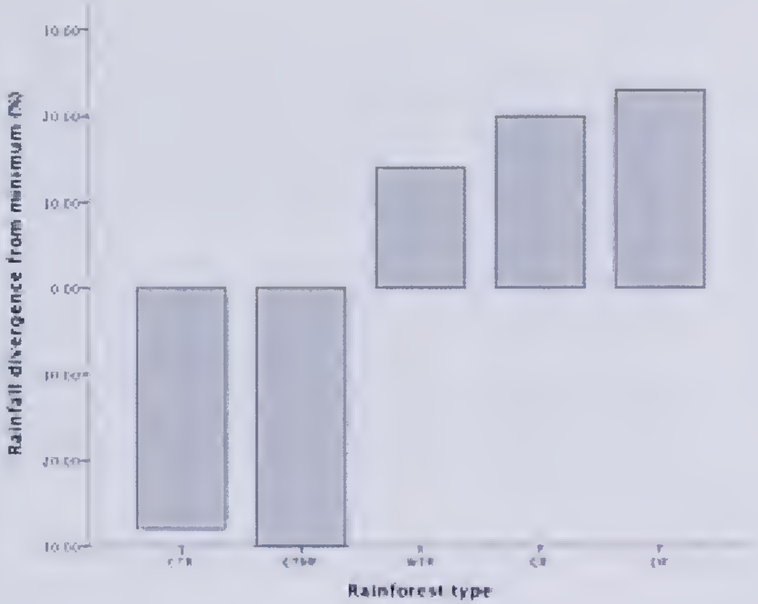

Fig. 1. Average divergence (percentage) from minimum annual rainfall requirement for rainforests of Victoria under a lowere emissions scenario in 2070.

as a landscape 'trap'; ecosystem modification occurs to an almost entirely irreversible extent due to natural and anthropogenic disturbances causing a series of feedback processes (Lindenmayer *et al.* 2011). As previously mentioned, the effects of climate change will threaten the resilience systems of the cool temperate rainforest by reducing humidity, increasing fuel loads and increasing temperatures.

Inland regions such as the North East, Strzeleckis, Central Highlands and parts of East Gippsland are more at risk than coastal rainforest areas such as the Otway Ranges and Wilson's Promontory. The inland rainforest of the Central Highlands, for instance, has coexisted with fire for the last 40 millenia, however the most recent 2500 years has seen fire frequency and intensity increase (Baker *et al.* 2012). Every century, one or two high-intensity crown fires would disturb the rainforest but the damage would be minimal. This is due to the damp and humid resilience of the rainforest and the adjacent *Eucalyptus regnans* F.Muell. forest towering above the rainforest canopy (Baker *et al.* 2012). A high-intensity crown fire in neighbouring *E. regnans* forests affords some protection in that the crown fires will travel slowly and with reduced heat energy toward the crowns of the rainforest species as they stand much shorter than the giant eucalypts (Baker *et al.* 2012). Despite these protective mechanisms, in 2009 47% of the cool temperate rainforest in the Central Highlands of Victoria was burnt (Worley 2012). This suggests that the rainforest's ability to protect itself from fire was reduced due to the intensity and extreme conditions of the burn. In fact, 8.5% of Victoria's cool temperate rainforests were burnt in the 2009 fires, with 50% of the fires classed as 'severe' (Worley 2012). Not only has the intensity of fires increased, the occurrence of major bushfires in Victoria has steadily become more frequent since the 1850s. From 1850 to 1900, Victoria experienced an average of 0.4 major bushfires per decade; from 1900 to 1950, this jumped to an average of 2.4 major bushfires per decade and from 1950 to 2000 the frequency increased again to an average of 3.4 major bushfires per decade (Bryant 2009).

Table 3. Implications of fire on Victoria's cool temperate rainforest due to climate change according to location. (After BOM 2012; Hennessy *et al.* 2005; Anon in *SMH* 2009; Bushfire CRC 2006; CSIRO 2011; Forest encyclopedia 2008).

Areas covered by Rainforest	Current fire season	Predicted fire risk increase with climate change			Impacts of climate change on fire			Predictions
		2020	2050	Risk due to location	Intensity (heat)	Frequency (number)	Extent (size)	
North East	December – February	4–25%	15–70%	High	+	+	+	- High risk of fire due to inland location - Should fire occur, intensity, frequency and its extent would increase due to climate change - Likely to be converted to sclerophyll forest
Otways	December – May	4-25%	15–70%	Low	+	+	+	- Low risk of fire due to proximity to coast - Should fire occur, intensity, frequency and its extent would increase due to climate change - Possibility of being converted to sclerophyll forest
Wilson's Promontory	December – February	4-25 %	15–70%	Low	+	+	+	- Low risk of fire due to proximity to coast - Should fire occur, intensity, frequency and its extent would increase due to climate change - Possibility of being converted to sclerophyll forest
Strzeleckis	December – February	4-25 %	15–70%	High	+	+	+	- High risk of fire due to land location - Should fire occur, intensity, frequency and its extent would increase due to climate change - Likely to be converted to sclerophyll forest
Central Highlands	December – February	4-25 %	15–70%	High	+	+	+	- High risk of fire due to inland location - Should fire occur, intensity, frequency and its extent would increase due to climate change - Likely to be converted to sclerophyll forest
East Gippsland	September – February	4-25 %	15–70%	Low–High	+	+	+	- Low to high risk of fire due to inland and coastal location - Should fire occur, intensity, frequency and its extent would increase due to climate change - Low to high likelihood of being converted to sclerophyll forest

Table 4. The potential effects of climate change on key species of Victoria's cool temperate rainforests. * CH = Central Highlands, EG = East Gippsland, NE = North East, OT = Otways, STRZ = Strzeleckis, WP = Wilson's Promontory. (After Boland *et al.* 1984; BoM and Walsh 1993; Conn 1993; Costermans 2009; Floyd 2008; Francis 1981; Jordan *et al.* 1992; Large and Braggins 2004; Wilkinson and Jennings 1993). N.B. Although these are key species, none are restricted to Cool Temperate Rainforest, or Victoria.

Tree Species	Region*	Rainfall		Fire	Implications	
		Required annual (mm)	2070 prediction at lower emissions (mm)		Plant species	Cool Temperate Rainforest
Acacia melanoxylon	CH, EG, OT, WP	750–1500	820	Requires disturbance to regenerate	Due to regeneration of seed with fire and low water stress, *A. melanoxylon* will persist	Will persist in all regions as part of sclerophyll forest
Atherosperma moschatum	STRZ, WP	1000–2000	870	Limited fire resistance	Due to high risk of fire and high water stress, not likely to persist in habitat	Will recede to the most sheltered pockets, topographically
Eucalyptus obliqua	EG	500–2400	878	Fire tolerant/requires disturbance to regenerate	Due to tolerance of/and regeneration with fire and very low water stress, *E. obliqua* will persist	Will become a dominant of sclerophyll forest in inland locations
Nothofagus cunninghamii	CH, OT, STRZ	1100–2500	820	Limited fire adaptation/ resistance	Due to high fire risk and extreme water stress, not likely to persist in habitat	Will recede to the most sheltered pockets, topographically
Dicksonia antarctica	OT, STRZ, WP	900–1700	875	Fire resistant	At risk due to water stress	May recede to the most sheltered pockets

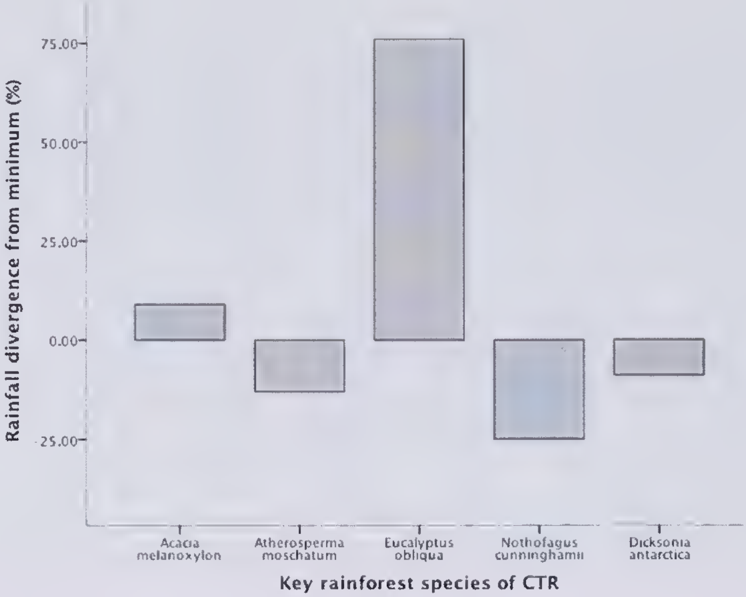

Fig. 2. Average divergence (percentage) from minimum annual rainfall requirement for key rainforest species.

Key species of cool temperate rainforests

To get a better understanding of the effects climate change will have on cool temperate rainforest, it is important to study the key canopy species that constitute the forest. The restrictions on distribution, required versus predicted rainfall parameters and fire adaptations of each species, give key insights into how climate change and broad-scale disturbance, such as fire, may affect each species, and the implications this will have for cool temperate rainforests (Table 4).

In 2070, at lower emissions predictions, *Acacia melanoxylon* R.Br. and *Eucalyptus obliqua* L'Her. will receive annual rainfall that sits well above their minimum requirements; 76% above minimum required annual rainfall in the case of *Eucalyptus obliqua*. By contrast, *Atherosperma moschatum, Nothofagus cunninghamii* and *Dicksonia antarctica* Labill. will all receive less rainfall than their current lower thresholds (Table 4; Fig. 2).

Acacia melanoxylon and *Eucalyptus obliqua* are both well adapted to fire and neither species is restricted to cool temperate rainforest or to Victoria. Therefore, should a fire occur, these two species are likely to persist and become dominant in the sclerophyll forest that will eventuate with climate change and increasing fire frequency.

Atherosperma moschatum and *Dicksonia antarctica* are both found in multiple regions as well as beyond Victoria (RBG 2012) and neither is restricted to cool temperate rainforest. Where they occur on coasts, they may be at lower risk to fire but may become less dominant in inland rainforests. *A. moschatum* does, however, have foliage with low flammability due to high moisture and low energy content; studies show that its leaves do not combust until >60% of moisture content is lost (Baker *et al.* 2012). This is in contrast to the leaves of many eucalypt species that will ignite when <40-50% of moisture has been lost (Baker *et al.* 2012).

A key dominant species of Victoria's cool temperate rainforests is *Nothofagus cunninghamii.* This species is restricted to habitats in Victoria and Tasmania. It has some adaptation to fire in its fire-responsive coppice shoots and may have bursts of regrowth after a fire with reproduction occurring either sexually or vegetatively (Howard 1981; Baker *et al.* 2012); however,

once a stand of *Nothofagus* is broken up by a fire, the remaining trees no longer have the protection of moisture, low temperatures and limited fuel on the forest floor that the dominant stand had, and are less resistant to the damaging effects of fire (Howard 1981). In the Central Highlands in the 2009 fires, the individuals of *N. cunninghammi* that grew in low numbers as understorey to *E. regnans* or in small patches of rainforest were all killed; Pappas (cited in Baker *et al.* 2012: 187) noted that rainforest taxa did not survive the fires unless they occurred in strips of rainforest that were 50 metres wide or more (Baker *et al.* 2012). These examples demonstrate that the resilience of the species is not necessarily found in the individual. The damaged stand is then likely to burn again, which will continue the process of degradation. Once this positive feedback loop has begun, the fate of the species is compromised.

It is predicted that *Nothofagus cunninghamii* will be receiving 25% less rainfall than its minimum annual requirements. The inability of *Nothofagus* to adapt to lower rainfall levels that came about in the Tertiary period, between 65 and 18 mya, confined it to cooler, wetter areas; so it is predicted that by 2070, the species will be forced to retreat once again to residual areas that are only a fraction of its current extent. *Nothofagus cunninghamii* also requires water, gravity and animals to transport its seeds rather than far-reaching wind or invertebrate vectors (Baker *et al.* 2012). It may persist in Tasmania and in the coastal sites of Victoria, but there is a high possibility that it will recede from its current locations in the inland Strzeleckis and Central Highlands, especially considering its limited dispersal mechanisms.

Conclusion

Factors such as slope, topographic position and competing vegetation must be considered to formulate a more comprehensive prediction of the effects climate change may have on the rainforests of Victoria (Lindenmayer 2009); however, it is still possible to predict the likely fate of Victoria's rainforests based on climate change predictions for 2030, 2050 and 2070.

Should fire, the risk of which is increased by climate change conditions, become more frequent and intense throughout Victoria, cool temperate rainforest will be greatly impacted. The dominant canopy species of Victorian cool temperate rainforests, *Nothofagus cunninghamii*, will be most at risk. Due to climate change, it will experience high water stress and be most susceptible to accumulated effects of increased fire events.

Rainforests, compared to other vegetation types of Australia, are relatively persistent; with the predicted temperature, rainfall and fire regime changes resulting from climate change and continued degradation by humans, Victoria's rainforests may be very different by 2070.

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References

Anon (2009) Bushfire ferocity linked to climate change, *The Sydney Morning Herald*, 9 February 2009, retrieved 5 August 2012, <http://www.smh.com.au/environment/climate-change/bushfire-ferocity-linked-to-climate-change-20090209-8235.html>

Baker PJ, Simkin R, Pappas N, McLeod A and McKenzie M (2012) Fire on the mountain: A multi-scale, multi-proxy assessment of the resilience of cool temperate rainforest to fire in Victoria's Central Highlands. In *Peopled landscapes: archaeological and biogeographic approaches to landscapes*, pp. 377–389. Ed SG Haberle and B David (ANU E Press: Canberra)

Beadle NCW (1981) *The Vegetation of Australia*. (Cambridge University Press: Cambridge)

Boland DJ, Brooker MIH, Chippendale GM, Hall N, Hyland BPM, Johnston RD, Kleinig DA and Turner JD (1984) *Forest Trees of Australia*. 4 edn, (Thomas Nelson Australia and CSIRO: Melbourne)

Bowman DJS (2000) *Australian Rainforests: Islands of green in a land of fire*. (Cambridge University Press: Cambridge)

Bryant C (2009) Victoria, understanding bushfire: trends in deliberate vegetation fires in Australia, (Australian Government) retrieved 2 October 2013, <http://www.aic.gov.au/documents/7/9/8/%7B7982F769-0EA0-4416-A040-B6056BC0DD06%7D)tbp027_03_vic.pdf>

Bureau of Meteorology (2012) Bushfireweather, (Bureau of Meteorology) retrieved 5 August 2012. <http://www.bom.gov.au/weather-services/bushfire/about-bushfire-weather.shtml>

Bureau of Meteorology and Walsh NG (1993) Climate of Victoria. In *Flora of Victoria, Vol 1, Introduction*, pp. 47–60. Ed DB Foreman and NG Walsh. (Reed International Books (Inkata Press): Melbourne)

Busby JR (1986) A biogeoclimatic analysis of *Nothofagus cunninghamii* (Hook.) Oerst. in southeastern Australia. *Australian Journal of Ecology* **11**, 1–7.

Busby JR and Brown MJ (1994) Southern Rainforests. In *Australian Vegetation*. 2 edn, pp. 131–155. Ed RH Groves. (Cambridge University Press: Melbourne)

Bushfire Cooperative Research Centre (2006) Climate change impacts on fire (Bushfire CRC) retrieved 6 August 2012, <http://www.bushfirecrc.com/sites/default/files/fire-updates/fireupdate- 1_2006-06.pdf>

Conn BJ (1993) Natural regions and vegetation of Victoria. In *Flora of Victoria, Vol 1, Introduction*, pp. 79–158. Ed DB Foreman and NG Walsh (Reed International Books (Inkata Press): Melbourne)

Costermans L (2009) *Native trees and shrubs of south-eastern Australia*. 2 Edn. (Reed New Holland: Chatswood, NSW)

Commonwealth Scientific and Industrial Research Organisation (2011) Fireweather (CSIRO) retrieved 5August 2012, <http://www.csiro.au/en/Outcomes/Climate/Adapting/Climate-Change-Fire-Weather.aspx>

CSIRO (2011) Fuel moisture content and bushfire behaviour (CSIRO) retrieved 6 August 2012, <http://www.csiro.au/en/Outcomes/Safeguarding-Australia/FuelMoistureAndBushfires.aspx>

Floyd AG (2008) *Rainforest trees of Mainland South-eastern Australia*. 2 edn. (Terania Rainforest Publishing: Lismore, NSW)

Forest Encyclopedia Network (2008) The Encyclopedia of Southern Fire Science — Fire intensity (Forest Encyclopedia Network) retrieved 6 August 2012, <http://www.forestencyclopedia.net/p/p486/>

Francis WD (1981) *Australian Rain-Forest Trees*. 4 edn. (Australian Government Publishing Service: Yennora, NSW)

Howard TM (1981) Southern Closed Forests. In *Australian vegetation*. 1 edn. pp. 102–119. Ed RH Groves. (Cambridge University Press: Cambridge)

Jarman SJ and Brown MJ (1983) A definition of cool temperate rainforests in Tasmania. *Search*, **14**, 81–87.

Jordan G, Patmore C, Duncan F and Luttrell S (1992) The effects of fire intensity on the regeneration of mixed forest tree species in the Cleer Hill/Mount Wedge Area. (Tasforests, Forestry Commission: Tasmania) retrieved 8 August 2012 http://117.55.239.235/assets/0000/0470/article_3.pdf

Large MF and Braggins E (2004) *Tree Ferns* (CSIRO: Collingwood)

Lindenmayer D (2009) *Forest pattern and ecological process: a synthesis of 25 years of research*. (CSIRO Publishing: Collingwood, Victoria)

Lindenmayer D, Hobbs RJ, Likens GE, Krebs CJ and Banks SC (2011) Newly discovered landscape traps produce regime shifts in wet forests. *PNAS*, **108**, 15887–15891.

Mackey BG, Keith H, Berry SL and Lindenmayer DB (2008) *Green Carbon: The role of natural forests in carbon storage*. (ANU E Press: Canberra)

Peel B (1999) *Rainforests and cool temperate mixed forests of Victoria* (Department of Natural Resources and Environment: East Melbourne)

Read J and Busby JR (1990) Comparative responses to temperature of the major canopy species of Tasmanian cool temperate rain-forest and their ecological significance. II. Net Photosynthesis and Climate Analysis. *Australian Journal of Botany* **38**, 185–205.

Royal Botanic Gardens Melbourne (2012), *Dicksonia antarctica* at the Royal Botanic Gardens Melbourne (RBG) retrieved 14 August 2012, http://www.rbg.vic.gov.au/dbpages/rbgcensus/index.php/census/species_detail/3927

Victorian Climate Change (2008) Climate change in Victoria: 2008 Summary (State Government of Victoria) retrieved 1 August 2012. <http://www.climatechange.vic.gov.au/__data/assets/pdf_file/0020/73172/DSEstatesummaryWEB.pdf>

Victorian Climate Change (2011a) Climate change in the Corangamite region (State Government of Victoria) retrieved 1 August 2012. <http://www.climatechange.vic.gov.au/__data/assets/pdf_file/0017/73070/Corangamite_WEB.pdf>

Victorian Climate Change (2011b) Climate change in East Gippsland (State Government of Victoria) retrieved 1 August 2012, http://www.climatechange.vic.gov.au/ _data/assets/pdf_file/0003/73119/EastGippsland_ WEB.pdf

Victorian Climate Change (2011c) Climate change in the North East region (State Government of Victoria) retrieved 1 August 2012, http://www.climatechange.vic.gov.au/__data/assets/pdf_file/0020/73118/NorthEast_WE B.pdf

Victorian Climate Change (2011d) Climate change in the Port Philip and Westernport region (State Government of Victoria) retrieved 1 August 2012, <http://www.climatechange.vic.gov.au/__data/assets/pdf_file/0003/73029/PPWP_WEB .pdf>

Victorian Climate Change (2011e) Climate change in West Gippsland (State Government of Victoria) retrieved 1 August 2012, http://www.climatechange.vic.gov.au/__data/assets/pdf_file/0013/73120/WestGippsland _WEB.pdf

Wilkinson G and Jennings S (1993) Survival and recovery of *Eucalyptus obliqua* Regeneration following Wildfire (Tasforests, Forestry Commission: Tasmania) retrieved 8 August 2012. http://www.forestrytas.com.au/assets/0000/0439/tf_5_article_1.pdf

Worley M (2012) *Impacts of the 2009 Kilmore East–Murrindindi bushfires on cool temperate rainforest in the Victorian Central Highlands: Black Saturday Victoria 2009 – Natural values fire recovery program* (Department of Environment and Sustainability: Melbourne).

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One Hundred Years Ago

Plant distribution in the Healesville District

BY REGINALD KELLY

Eucalyptus obliqua is veritably a messmate to all those mentioned, being found in association with them, and usually the dominant partner, from the lowest to the highest ground. It is found on the river banks, sometimes hanging over the water in almost willow-like form, and at the tops of the mountains as a straight-trunked, magnificent timber tree.

From *The Victorian Naturalist* **XXXI**, p. 58, August 6, 1914

Sheila Houghton

18 March 1928 – 16 September 2014

Sheila Houghton, who has died at the age of 86, was a highly active and much valued member of the FNCV. Sheila was born at home in Herne Bay, Kent. She had a passion for words, literature and grammar and trained as a librarian at London University. In 1953, she met Neville Houghton, an Australian, in the staff room at Islington Central Library in London, and they were married in September the following year. They moved to Perth in 1958, and later to Melbourne.

In Australia, Sheila developed a love for the nature of her adopted country, particularly its botany and fungi. She completed a short plant identification course run by the CAE at Melbourne University, and Jon Martindale, a work colleague at Oakleigh Library, suggested she join the FNCV. She was elected a member of the Club in July 1972. Jon had joined shortly before, and soon after became the Club's librarian.

Sheila's close involvement with the Club began in the early 1980s. In August 1981, she was asked to fill a vacancy on the FNCV Council. She agreed, and thus began a long and productive association with the Club that extended almost 30 years. With the exception of the year 1990–1991, during which she and Neville worked in China, Sheila was an office bearer of the Club in every year over that period.

Once on Council, Sheila realised the Club effectively had no secretary — so she volunteered her services and filled that rôle until the 1982 AGM. She was then elected Secretary and served until January 1985. Sheila became the Honorary Librarian in 1985 and worked in that capacity until April 2011. She was also elected as a Vice-President in 1985, and in January 1986 reluctantly became Acting President (until the following AGM), when Brian Smith unexpectantly stepped down as President. Sheila was Vice-President again in 1988 –1990.

In the lead up to the Club moving to its new premises in Blackburn in 1996, Sheila was a member of the Property Sub-committee that was formed; other members included the President and Secretary. Sheila was a driving force in the refitting of the building, laying out the design and ensuring that the spaces allocated for different aspects of the Club's activities were adequate, and that all work complied with government and local regulations.

Sheila was made an Honorary Life Member of the FNCV in December 1996, in recognition of her long and significant service to the Club. This did not lead to her resting on her laurels: she had been Secretary to the ANHM Committee since 1987 and, except for the break in 1991, continued in that position until 1999. She later wrote that it was one of the most enjoyable and interesting jobs she took on for the Club. In 1999 she added to her workload by being officially confirmed as FNCV Archivist.

While mediating the business of the Club through these various positions, Sheila was also engaging in field excursions, attending meetings, exhibiting specimens, and writing. From 1985 to 2009 she published six Naturalists Notes in *The Victorian Naturalist,* and numerous pieces on a range of topics in *Field Nats News.* Through her work in ordering the Club's Archives, Sheila had a detailed knowledge and appreciation of FNCV history. In 1987 she wrote a short history of the ANHM, using *The Victorian Naturalist,* Council minutes and letters as sources. Through unfortunate circumstances, all the ANHM records had been destroyed so Sheila felt that something should be done to try to retrieve as much of the history as possible. Her love of history also prompted her to write *Leaves from our history,* which was part of the celebration of the Club's 125th anniversary.

Sheila's devotion to the FNCV was coupled with her desire to make the information held

in the Club's archives accessible to the widest audience. To this end she compiled the *Index to Southern Science Record* (2002); and *Index to the Field Nats News 1991 – 2009* (2010).

Sheila's contribution to the FNCV is unparalleled in recent decades and she will be greatly missed by the many friends and acquaintances she had within the membership, and on whom she was an influence. A small measure of the respect and appreciation the Club had for Sheila was expressed at the 2010 FNCV Christmas party when the space she occupied for so many years was named The Sheila Houghton Library and Archive. Sheila's presence and influence will live on within the Field Naturalists Club of Victoria.

I am pleased to thank Sheila's husband Neville and their children Alison Viney and Chris Houghton for their assistance in writing this tribute.

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